ξ04598

PLANT STUDY

IN

SCHOOL, FIELD & GARDEN

A TEXT-BOOK ON RURAL SCIENCE AND GARDENING

BY

JOSEPH S. BRIDGES,
M.A., B.Sc., LL.D., Ph.D.,
OF THE LONDON AND CAMBRIDGE UNIVERSITIES; OF THE INNER TEMPLE.
BARRISTER-AT-LAW;
FELLOW OF THE GEOLOGICAL AND CHEMICAL SOCIETIES, LONDON;
CHIEF EDUCATION OFFICER, WILLESDEN; LATE ORGANISING INSPECTOR AND
DIRECTOR OF HIGHER EDUCATION, WALTHAMSTOW;
PROFESSOR OF BIOLOGY, CITY OF LONDON COLLEGE.

AND

ARTHUR J. DICKS,
B.A., B.Sc. (Lond.).
HEADMASTER OF THE EUCLID STREET SECONDARY SCHOOL SWINDON
LATE PRINCIPAL OF THE COUNTY HIGH SCHOOL, AND TECHNICAL INSTITUTE,
WALTHAMSTOW,
JOINT AUTHOR OF "INORGANIC CHEMISTRY."

London:
HERBERT RUSSELL,
35 & 36 TEMPLE CHAMBERS, E.C. 4.

FIRST EDITION, APRIL, 1908.
REPRINTED, FEBRUARY, 1909.
REPRINTED, MARCH, 1910.
REPRINTED, JANUARY, 1911.
REPRINTED, MAY, 1912.
REPRINTED, FEBRUARY, 1914.
REPRINTED, NOVEMBER, 1916.
REPRINTED, OCTOBER, 1919.
REPRINTED, OCTOBER, 1921.
REPRINTED, JULY, 1924.
REPRINTED, JANUARY, 1926.

Printed in Great Britain,
By HENRY PALMER & Co., London.

Preface.

The four characteristics of this Text Book on Plant Study will be found to be:—

(i.) The exclusion of mere terms and the emphasis given to vital processes.

(ii.) Its experimental and practical nature.

(iii.) The abundance of original drawings, on which the text is based.

(iv.) The useful Summaries and Practical Exercises given at the end of each chapter.

(i.) Text Books in Biology, especially on the Botanical side, are too often a catalogue of difficult terms and Latinisms, while the living processes themselves are overlooked or insufficiently described.

(ii.) Science is useless, unless it is experimental, and if it is made so, its educational value cannot be over-rated. The experimental part of the subject in school is now often supplemented by work in the school greenhouse and garden, with excellent results.

(iii.) Many of the drawings have been made directly from the specimens prepared and experiments performed by young students—work that has aroused the deepest interest in the study of plant life. These drawings, the copyright of which we retain, by the courtesy of the Publishers, deserve the special attention of the student, and when he cannot obtain actual specimens, his time will be well spent in reproducing some of them. The value of hand and eye training in this dual connection is evident—the making of a detailed drawing compels attention. Mere mechanical copying, however, must never displace the drawing from the real thing when it can possibly be obtained.

For the photographs illustrating the ecological side of the subject, we are indebted to the Sciopticon Co., whose unique series of lantern slides have been invaluable to us in our lecture work.

(iv.) The Summaries given at the end of each chapter will prove very useful for Preliminary and Final Certificate Students of the Board of Education, and for the London Matriculation, in that necessary revision which must precede any examination. Following these Summaries extra Practical Work has been suggested for the use of more enthusiastic students.

(v.) We beg to add one caution. There is a distinct danger of the Student regarding the plant as a conscious organism capable of volition. We have accordingly made liberal use of inverted commas when, for simplicity's sake, we have employed phrases which might otherwise be taken to imply volition.

JOS. S. BRIDGES.

ARTHUR J. DICKS.

Walthamstow Technical Institute,

February, 1908.

Table of Contents.

PART I.

PLANT LIFE.

CHAPTER I.

PAGES.

Comparison of the Mature Plant with Seedling and Seed .. .. 1—9

Sect. 1. The Structure of a Complete Plant.
" 2. The Young Bean Plant.
" 3. The Bean Seed.

CHAPTER II.

Structure of Seeds .. .. 10—15

Sect. 1. Seeds with Two Seed Leaves:—
Pea, Broad Bean, Laburnum, Vegetable Marrow, Acorn, Sycamore, Sunflower.
" 2. Seeds with One Seed Leaf:—
Maize, Wheat.
" 3. A Seed with Many Seed Leaves:—
Pine.

CHAPTER III.

Conditions of Germination .. .. .. 16—24

I.—THE SEED IN RELATION TO WATER AND AIR.

Sect. 1. The Penetrating Power of Water.
" 2. Capillarity.
" 3. Capillarity in the Soil.
" 4. Capillarity in the Seed.
" 5. Diffusion in the Seed.
" 6. Composition of the Air from a Respiratory Point of View.
" 7. True Nature of Respiration
" 8. Do Seeds Respire?
" 9. Is Oxygen necessary for the Seed's Respiration?
" 10. Is Heat Produced by the Respiration of a Seed?

CHAPTER IV.

PAGES.

Conditions of Germination .. .. 25—34

II.—GROUND AIR AND MOISTURE.

Sect. 1. The Ground Air—Its Presence and Amount.
,, 2. Composition of the Ground Air.
,, 3. Movement of the Ground Air.
  (i.) Effect of the Wind.
  (ii.) Effect of Barometric Pressure—Principle of Barometer.
  (iii.) Effect of Temperature.
  (iv.) Effect of Heavy Rain.
,, 4. Effect of Ground Air Movements on Seeds Underground.
,, 5. Necessity of Rain—the Rain Gauge.
,, 6. Effect of Amount of Moisture in the Atmosphere.
,, 7. Temperature and the Seed.
,, 8. Temperature of the Soil and the Air above.

CHAPTER V.

Germination .. .. 35—47

Sect. 1. Germination Methods.
,, 2. Germination of Plants with Two Seed Leaves:—
  (*a*) The Runner Bean, (*b*) Measurement of its Lifting Power, (*c*) The Pea, (*d*) The Acorn, (*e*) The Beech, (*f*) Honesty, (*g*) Buckwheat, (*h*) Sycamore, (*i*) Sunflower, (*j*) Hemp.
,, 3. Germination of Plants with One Seed Leaf:
  (*a*) Maize, (*b*) Wheat, (*c*) Barley, (*d*) Date.
,, 4. Germination of a Plant with Many Seed Leaves.

CHAPTER VI.

Food .. .. 48—56

Sect. 1. The Nature of Protoplasm.
,, 2. Requirements of Protoplasm.
,, 3. Ideal Foods.
,, 4. The Complexity of Food Material.
,, 5. Characteristic Tests for Foods.
,, 6. The Meaning of Digestion.

PAGES

Sect. 7. Examples of Digestion :—
 (i.) In Animals.
 (ii.) In Plants.
„ 8. Foods Stored up in Seeds :—
 (*a*) Starch, (*b*) Proteid, (*c*) Fat, (*d*) Cellulose.
„ 9 Amount of Food Stored up in Seeds.

CHAPTER VII.

The Varieties, Functions and Behaviour of Roots .. .. 57—65

Sect. 1. The Work done by Roots.
„ 2. The Two Chief Varieties of Root Systems.
„ 3. Other Functions of Roots.
„ 4. Meanings of the Words "Irritability" and "Stimulus."
„ 5. The Root Considered as an Irritable Organ.
 (i.) Influence of Gravity.
 (ii.) Influence of the Position of the Parent Body.
 (iii.) Influence of Moisture in the Soil.
 (iv.) Influence of Light.
„ 6. How Irritability Aids Root Functions.

CHAPTER VIII.

The Structure and Work of Roots .. .. 66—77

A. HOW THE STRUCTURE OF A ROOT FITS IT FOR ITS LIFE AND WORK IN THE SOIL.

Sect. 1. The Root-Cap.
„ 2. The Root Hairs.
„ 3. The Position of the Strong Tissues in a Young Root.
„ 4. The Protection of the Young Root in its Earlier Stages of Growth.

B. HOW ROOTS ABSORB WATER AND MINERAL SUBSTANCES.

Sect. 5. Osmosis.
„ 6. The Root Hairs Absorb Raw Food Materials by Osmosis.
„ 7. Turgidity.
„ 8. Root Pressure.
„ 9. Absorption.

PAGES.

Sect. 10. Factors Influencing the Amount of Absorption.
„ 11. Selective Action of Roots.
„ 12. Region and Rate of Growth.

CHAPTER IX.

The Stem .. .. 78—96

Sect. 1. Functions.
„ 2. External Appearance of Stems.
„ 3. Growth of Stems in Length.
„ 4. Buds.
„ 5. Their Protected Positions.
„ 6. How Buds are Protected in Themselves.
„ 7. Contents of Buds.
„ 8. Arrangements of Leaves in Buds.
„ 9. The Presence of Flowers in Buds.
„ 10. Shapes of Buds.
„ 11. Elongation of the Stem.
„ 12. Examination of Scars found on Woody Stems.
„ 13. The History of a Branch.

CHAPTER X.

The Stem as a Conducting Organ .. .. 97—111

How the Internal Structure of Stems fits them for their Work.

Sect. 1. Arrangement of the Vascular Bundles in Green Stems.
„ 2. Use of the Soft Region in Green Stems.
„ 3. Dual Nature of the Conducting Tissues.
„ 4. Summary of the Conducting Tissues.
„ 5. Detailed Examination of the Wood and Bast.
„ 6. Necessity of Increase in Girth in Stems.
„ 7. Mechanism by which Stems Increase in Thickness.
„ 8. Annual Rings.
„ 9. Medullary Rays.
„ 10. Extent of Living Tissue in Stems.
11. Use of the Medullary Rays.
„ 12. Origin of Knots in Wood.
„ 13. Healing of Wounds on Stems.

CHAPTER XI.

PAGES.

Stems Performing Special Functions .. .. 112—125

Sect. 1. Creeping Stems.
„ 2. The Strawberry Plant.
„ 3. The Perennial Sunflower.
„ 4. Other Fleshy Creeping Underground Stems:—
  (*a*) Iris or Flag.
  (*b*) Solomon's Seal.
„ 5. Tubers:—
  (*a*) The Artichoke.
  (*b*) The Potato.
„ 6. Bulbs and Corms:—
  (*a*) Bulbs.
  (*b*) Corms.
  (*c*) Life Cycle of a Crocus Corm.
  (*d*) Questions for the Student.

CHAPTER XII.

The Irritability of Stems .. .. 126—138

STEMS AS SENSITIVE ORGANS.

Sect. 1. The Effect of Light:—
  (*a*) The Effect on the Rate of Growth.
  (*b*) The Effect on the Total Length of Stems.
  (*c*) Biological Significance of this Effect.
  (*d*) Directive Action of Light on Stem Growth.
  (*e*) Which Constituents of White Light have a Directive Action?
  (*f*) Influence of Light on Creeping Stems.
„ 2. The Effect of Gravity:—
  (*a*) On Main Stems;
  (*b*) On Lateral and Creeping Stems.
„ 3. Influence of Contact:—
  (*a*) The Nutation of Stem Tips.
  (*b*) The Pronounced Nutation of Twining Stem Tips.
  (*c*) How a Twining Stem clasps its Support.
  (*d*) Stem Tendrils.
  (*e*) Behaviour of Tendrils.
  (*f*) Leaf Tendrils.

CHAPTER XIII.

PAGES.

The Structure of the Leaf .. .. 139—151

Sect. 1. Main Functions of Leaves.
" 2. Arrangement of Leaves on Stems.
" 3. The External Appearance of a Typical Leaf:—
  (*a*) The Stalk.
  (*b*) The Thin Leaf Tissue.
  (*c*) The Veins.
  (*d*) Further Contrivances Helping to Present the Leaves to the Light.
  (*e*) Leaf Mosaics.
" 4. The Internal Structure of Leaves:—
  (*a*) The Surface Skins of the Leaf.
  (*b*) The Soft Green Cells of the Leaf.
  (*c*) Sensitive Nature of the Living Material in these Cells.
  (*d*) The Veins of the Leaf.

CHAPTER XIV.

Assimilation .. .. 152—164

Sect. 1. Conditions for the Formation of Chlorophyll.
" 2. Experiments on Starch Formation in Leaves.
" 3. The Work of the Green Colouring Matter.
" 4. Chemical Nature of this Work.
" 5. Names given to this Food-making Process.
" 6. The Effects of Vegetation upon the Atmosphere.
" 7. Comparison of the Effects of Animals and Plants on the Composition of the Atmosphere.
" 8. The Nutritive Processes of Plants and Animals.
" 9. How Starch Feeds a Plant.
" 10. Sugar or Starch Formation does not Represent the whole Process of Food Manufacture in Plants.

CHAPTER XV.

PAGES.

Transpiration .. .. 165—175

Sect. 1. A Plant gives off Water from the Under Sides of its Leaves.
,, 2. A Plant Possesses the Power of Sucking up Water through its Stem.
,, 3. Paths of the Upward Current of Water in Stems.
,, 4. The Transpiration Current (or Ascending Sap).
,, 5. Distinction between the Transpiration Current and Transpiration.
,, 6. Transpiration is Modified Evaporation.
,, 7. Details of the Transpiration Process in the Leaf.
,, 8. Measurement of the Amount of Water Absorbed and Evolved by a Shoot.
,, 9. The Potometer.
,, 10. Experiments with the Potometer.
,, 11. Conditions affecting the Rate of Transpiration—Results of the above Experiments:—
  (*a*) Light: Details of Opening and Closing of the Stomata.
  (*b*) Humidity of the Atmosphere.
  (*c*) Wind.

CHAPTER XVI.

Flowers .. .. 176—189

Sect. 1. Vegetative and Sexual Reproduction.
,, 2. What is meant by a Sexual Process.
,, 3. The Biological Significance of Flowers.
,, 4. The Sexual Cells in Flowers:—
  (*a*) The Male Cells.
  (*b*) The Female Cells.
,, 5. The Necessity of Pollination. Pollination and Fertilisation.
,, 6. Mechanism of Pollination.
,, 7. Flowers of Various Complexity:—
  A. Simple Unisexual Flowers:
    (*a*) Maize, (*b*) Willow, (*c*) Poplar, (*d*) Hazel, (*e*) Oak.

PAGES.

B. Simple Bisexual Flowers:
(*a*) Common Grasses, (*b*) Sycamore, (*c*) Buttercup, (*d*) Marsh Marigold.

CHAPTER XVII.

Flowers of Greater Complexity and their Mechanisms .. .. 190—207

Sect. 1. Lengths of Insects' Tongues.
„ 2. Wallflower.
„ 3. Garden Pink.
„ 4. Hollyhock.
„ 5. Sweet Pea.
„ 6. Canterbury Bell.
„ 7. Cherry.
„ 8. Tobacco and Honeysuckle.
„ 9. Columbine, Larkspur and Monkshood.
„ 10. Pansy and Violet.
„ 11. Dead Nettle.
„ 12. Comfrey and Snapdragon.
„ 13. Primrose.
„ 14. Sunflower.
„ 15. Wind *versus* Insect Pollination.

CHAPTER XVIII.

Formation of Seeds and Fruits and their Dispersal .. .. 208—221

Sect. 1. Dispersal of Seeds and Fruits.
„ 2. Wind Dispersal.
„ 3. Seeds freed by a Strong Wind.
„ 4. Seeds forced away from the Parent.
„ 5. Seeds and Fruits of a Hairy Nature.
„ 6. Winged Fruits.

CHAPTER XIX.

Dispersal of Fruits and Seeds (*Continued*) .. 222—231

Sect. 1. Dispersal by Animals.
„ 2. Prickly Fruits.
„ 3. Nuts.
„ 4. Berries.
„ 5. Stone Fruits.
„ 6. Fruits with Attractive Flower Stalks.
„ 7. Dispersal by Water Agency.

CHAPTER XX.

PAGES.

The Plant and its Environment (I.) .. .. 232—243

Sect. 1. Introductory.
„ 2. Considerations of Light and Air.
„ 3. How Plants Share the Available Light.

CHAPTER XXI.

The Plant and its Environment (II.) .. .. 244—258

Sect. 1. Moisture.
„ 2. Its Conditions.
(*a*) Rainfall, (*b*) Wind, (*c*) Contour of the Land, (*d*) the Soil.
„ 3. Classification of Plants with Respect to the Amount of Water Available.
„ 4. Xerophytes.
„ 5. The Various Habitats of Xerophytes (*a*—*h*).
„ 6. Xerophytic Characters (*a*—*x*).

CHAPTER XXII.

The Plant and its Environment (III.) .. .. 259—272

Sect. 1. Water Plants:—
Their Condition of Life.
Their Form and Structure.
„ 2. Temperature and its Conditions:—
Latitude, Altitude, Wind, Depth of Roots in Soil, Amount of Moisture and Humus in the Soil.
„ 3. Main Factors in the Distribution of Plants.
„ 4. Typical Plant Societies.
„ 5. Synopsis of Conditions under which Plants Live.

CHAPTER XXIII.

General Review of Plant Life .. .. .. 273—282

Sect. 1. Germination.
„ 2. Roots.
„ 3. The Stem.
Sect. 4. The Leaf.
„ 5. Flowers and Fruits.
„ 6. Plant Ecology

PART II.

THE SCIENCE OF THE SOIL.

CHAPTER XXIV. PAGES.

The Formation and Geological Origin of Soils 283—299

Sect. 1. Soil and Subsoil.
„ 2. Formation of Soils.
(i.) Aqueous Agencies.
(ii.) Atmospheric Agencies.
(iii.) Chemical Agencies.
(iv.) Organic Agencies.
(v.) Igneous or Volcanic Agencies.
„ 3. The Relation of Minerals, Rocks and Soils to One Another.
„ 4. The Weathering of Granite.
„ 5. Geological Origin of Soils.
„ 6. Agricultural Characters of these Formations.

CHAPTER XXV.

The Composition and Character of Soils .. 300—318

Sect. 1. The Chemical Composition; Humus, Nitrates. Organic and Inorganic Matter.
„ 2. Physical Character of Soils, Sand and Clay, Mechanical Analysis, Lime and Liming.
„ 3. Physical Properties of Soils; Porosity, Capillarity, etc.
„ 4. Fertility of Soils. Active and Dormant Matters. Available Plant Food. Conditions of Fertility. Subsoil and "Pans." Experimental Plots.

CHAPTER XXVI.

Plant Food supplied by the Soil .. .. .. 319—328

Sect. 1. The Chemical Constitution of Plants.
„ 2. Plant Ash Fallacies.
„ 3. Water Cultures.
„ 4. Rotation of Crops.
„ 5. Source of C.H.O.N.S. and P. for the Plant (*See Summary*).

PART III.

PRACTICAL GARDENING.

CHAPTER XXVII.

PAGES.

Work done in the Garden (I.) .. .. .. 329—346

Practical Cultivation of Lettuces, Cabbages, Cauliflowers, Beans, Peas, Beetroot, Carrots, Turnips, Celery, Onions and Potatoes.

Kinds, Means of Propagation, Soil Required. Time for Sowing and Distances Apart, Diseases and Points of General Practical Interest. Amount of Seed required per Acre.

CHAPTER XXVIII.

Work done in the Garden (II.) .. .. .. 347—357

1. Propagation by Cuttings, Layering, Budding and Grafting.
2. Propagation by Corms and Bulbs.

A Scheme of Practical Horticulture,

DEMONSTRATION I.

The Soil and Its Preparation .. .. .. 358—359

Sect. 1. Preparation of Land for the Growth of Crops, and Practice in the Use of Implements.
„ 2. Rolling.
„ 3. Practice in the Use of Rake, and Preparation of Seed Beds.
„ 4. Practice in the Use of the Dutch Hoe.

DEMONSTRATION II.

Manures and Their Use .. .. 360—361

Sect. 1. Farmyard Manure.
„ 2. Sampling Different Kinds of Artificial Manures.
„ 3. Preparation of Liquid Manure.

DEMONSTRATION III.

PAGES.

Preliminary Cultural Operations .. .. .. 361—362

Sect. 1. Seed Sowing—Vegetables.
" 2. Transplanting Seedlings.
" 3. Planting Trees or Bushes.
" 4. Mixing Composts.
" 5. Potting.
" 6. Staking.

DEMONSTRATION IV.

Vegetable Culture .. .. 363—364

Sect. 1. Making Sets of Potatoes.
" 2. Preparing a Seed-Bed for Onions.
" 3. Sowing Peas.
" 4. Sowing Beans.

DEMONSTRATION V.

Propagation of Plants .. .. 365—367

Sect. 1. Making Cuttings.
" 2. Budding.
" 3. Grafting.
" 4. Layering.
" 5. Division of Herbaceous Plants.

DEMONSTRATION VI.

Principles of Flower Culture .. .. .. 367—370

Sect. 1. Potting Bulbs.
" 2. Planting Bulbs.
" 3. Sowing Flower Seeds in Pans and Boxes.
" 4. Potting Seedlings.
" 5. Bedding.

DEMONSTRATION VII.

Fruit Culture 370

Visit to a Fruit Farm.

DEMONSTRATION VIII.

Work under Glass .. .. 370—371

Sect. 1. Making Vine Eyes.
" 2. Visit to Fruit Houses.

Appendices 372

Index 410

PART I.

PLANT LIFE.

CHAPTER I.

Comparison of the Mature Plant with Seedling and Seed.

1. **The Structure of a Complete Plant.**—Any common flowering plant shows on examination an evident division into various parts widely differing from one another in appearance. If we seek the reason of this wide differentiation we find that the shape and structure of each part fit it for performing some particular work for the benefit of the whole plant. We will take a well-developed Scarlet-Runner bean plant as our example. (Figs. 1, 2.)

(*a*) Its root system (Fig. 2), if dug up entire, shows a main root which proceeds a considerable distance into the ground. From this many smaller roots arise and still smaller ones in turn from these. In this way the mass of roots intimately penetrates the soil region from which the plant derives its water and mineral substances. At the same time it affords an efficient attachment organ to anchor the plant in the soil.

(*b*) Its slender, branching stem, twining like a tendril up a strong support, performs two functions:—

(i.) It spreads out the leaves to the light in the best possible way.

(ii.) It conducts to them the raw food materials absorbed by the roots.

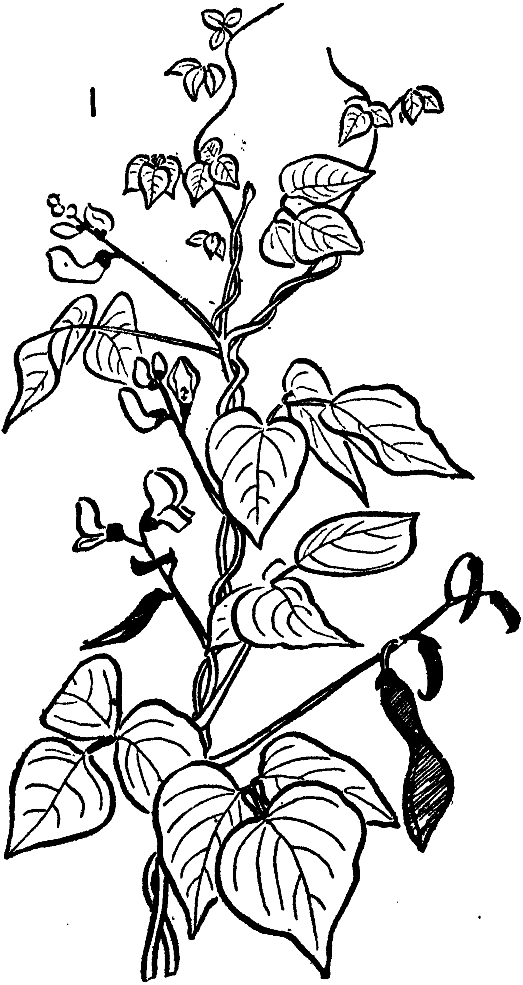


Fig. 1.—Upper portion of a mature Bean Plant, showing stems, leaves, flowers and fruits.

(c) Its leaves, each composed of three broad leaflets (Fig. 1), are thin, flat plates of tissue. They are arranged in well illuminated positions, since by the aid of sunlight they are capable of manufacturing the plant's real food (sugar) from raw materials supplied by the soil and the air. All the above organs—roots, stems and leaves—have for their primary function the nutrition of the present plant. Hence they are frequently called its vegetative organs. Later in the season, however, the food produced by their activity is devoted to the formation of flowers, fruits and seeds. Since these last-mentioned parts are primarily concerned with the formation of *new* individuals, they are grouped together as the reproductive organs of the plant.

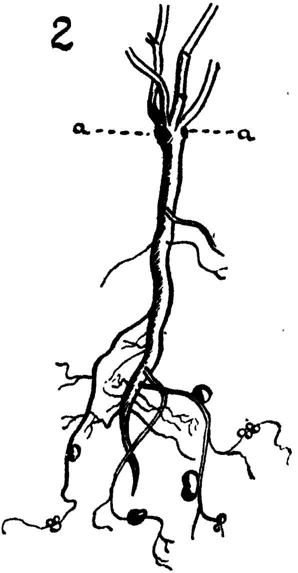


Fig. 2.—Lower portion of a mature Bean Plant, showing its root system.—(*a a*) Scars where the seed leaves have fallen.

(*d*) Its flowers are in groups, forming vivid "splashes" of red against the green background of the leaves. Each group of flowers is well held out by a long stalk; if this were not so they would be completely hidden amongst the thick foliage. The bright scarlet colour attracts insect visitors, and, as a result of their visits, fruits and seeds are produced.

(*e*) The long narrow pods which gradually grow out from the withered flowers are the fruits or seed-cases of the plant.

(*f*) The contained seeds (*i.e.* the beans), are the provision made by the plant to ensure the reproduction of its kind, for each bean contains a young plant capable of vigorous growth when placed under suitable conditions.

2. The Young Bean Plant.—It is interesting to compare an adult plant such as the above with another plant of the same kind in quite a young stage of its growth. A bean seedling has the appearance shown in Fig. 3A.

3A

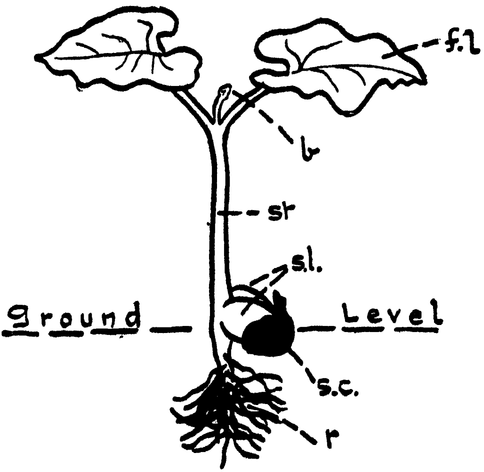


Fig. 3A.—A Bean Seedling.—(f.l.) Foliage Leaf; *(b.)* Bud; *(st.)* Stem; *(s.l.)* Seed Leaves; *(s.c.)* Seed Coat; *(r.)* Root System.

Above ground we see a firm upright stem whose terminal bud will carry on all future growth in length. Two foliage leaves already produced from this bud are expanded to the light and are actively engaged in manufacturing food. This food will be immediately utilised by the plant for the production of more leaves and a greater length of stem. The slightest comparison between these two plants (Figs. 1, 2, 3A) shows the relatively immense amount of food which must have been manufactured and utilised during the gradual acquisition of the adult condition. As each new leaf is formed, it at once serves as an additional food factory, and the products of its activity are forthwith expended in the production of more new stems and leaves.

Quite near the ground two leaves possessing a far different appearance will be noticed. These are the thick green seed-leaves. They are just appearing above ground, and are slightly assisting in the formation of food. They were originally contained in the seed; in fact, part of the seed coat can still be found adhering to them. Their original function was to serve as storehouses for the nourishment which has enabled the bean plant to commence growth when buried in the soil.

On such a small plant being dug up from the soil and the dirt removed from its root system, the latter will be found to present in miniature all the features of the mature root system. We find that the main root is the most prominent structure and that from it there arise four vertical rows of rootlets. This is clearly to be seen in very early stages of bean germination. (Fig. 3B.)

3B

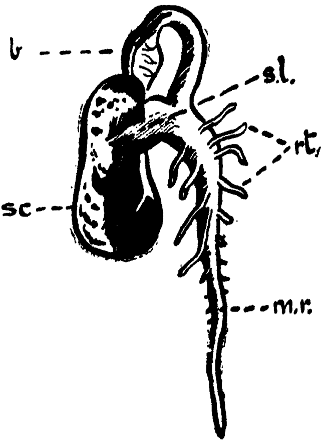
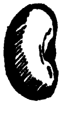
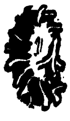


Fig. 3B.—Very early stage in the growth of a Bean Seedling.—(*b.*) Bud; (*m.r.*) Main Root; (*rt.*) Rootlets; (*s.c.*) Seed Coat; (*s.l.*) Seed Leaf.

3. The Bean Seed.—We will now examine a bean before germinating; a day's soaking of the seed will greatly facilitate our work.

Periodic observation whilst soaking shows that at first the tough seed coat becomes strongly wrinkled, later this is followed by an increase in size of the whole bean and finally the wrinkles disappear completely. (Figs. 4-6.) The wrinkled condition of the seed coat merely shows that it swells on absorbing moisture, and is thus too large for its as yet dry unswollen contents. The gradual disappearance of the wrinkles tells us that the seed within is absorbing more and more water, and if the seed be soaked too long a time it will be found to burst its coat. This


4.


5.

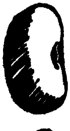

6.

Fig. 4.—An unsoaked Bean.
Fig. 5.—The same whilst soaking.
Fig. 6.—The same soaked.

artificial soaking goes on at a much more rapid rate than the absorption of water below ground under natural conditions of sowing. In the natural state the process is a long one, since the water supply is more precarious and much smaller. In this connection think how a good shower or two accelerates the appearance of seedlings above ground.

7.

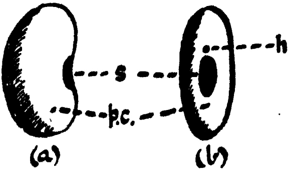


Fig. 7.—Structure of Bean Seed.—(*a*) Side view; (*b*) Front view.—(*s.*) Scar of Attachment; (*h.*) Small Hole where Root grows out; (*p.c.*) Protective Seed Coat.

Let us now proceed to a study of the soaked bean itself. Outside we see the tough seed coat. Down one side of this runs a long oval scar, marking the place where the stalk of the bean attached it to the pod. (Fig. 7.) If the bean be held between the thumb and finger and gently squeezed, a drop of water will be seen to exude from a small hole at one end of the scar. This hole is a very important structure for the first root always makes its appearance near it. It is of value to consider how the hole has arisen. In the bean flower (Fig. 8, *d*, *e*), there is a chamber (the ovary) which develops later into the bean pod. This chamber

8.

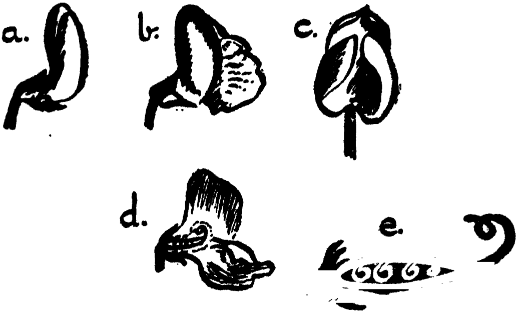


Fig. 8.—The Bean Flower.—(*a*, *b*) Side views of Bud and Flower; (*c*) Front view of Flower; (*d*) Longitudinal section of Fig. *b* (note the ovary or chamber in the centre of the flower); (*e*) Ovary from *d* enlarged to show the contained Ovules.

contains tiny bodies (ovules) attached to its wall, and these develop later into seeds (*i.e.* the beans). We have seen that the ripe bean has a seed coat, but if we could take an ovule in a very early stage we should find this coat absent entirely. Quite early, however, in the life of the ovule a ring-like out-growth appears as a collar (Fig. 9), just where the ovule joins its stalk; as this outgrowth develops it closely invests the ovule until finally the latter is completely enclosed except at its tip, which is shown diagrammatically in Fig. 9. This unprotected tip remains as the hole which we have already noticed. Why was the tip of the ovule left uncovered? This question will be fully answered later, but it may be mentioned here that the pollen grain grows downwards as a long thread (pollen tube), and after entering the ovary chamber it pierces the ovule through this same hole and renders possible the further development of the ovule into the seed.

9.

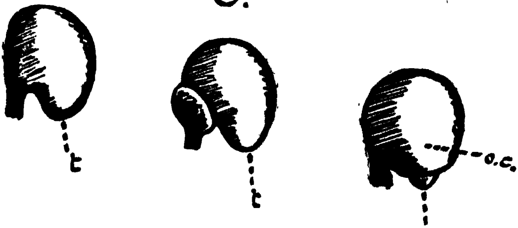


Fig. 9.—The upgrowth of the Coat of the Ovule.—(*t.*) Tip of the Ovule; (*c.*) Collar; (*o.c.*) Ovule Coat. The coat proceeds further than is shown in the last figure.

On removal of the seed coat the contents are seen to consist of two large fleshy lobes closely adpressed to each other by their inner faces. (Fig. 10B.) These are the seed leaves which were noticed above ground in the bean seedling (Fig. 3A), and whose scars are shown low down on the stem of the adult plant. (Fig. 2, *a a.*) Their present firm texture contrasts strongly with the shrivelled appearance they will show later in the life of the plant. In the seed they are filled as full as possible with nourishment. This is the store laid up by the "provident" parent in order that the offspring may have sufficient energy to grow through the soil to the light, for until a plant expands its green leaves to the light it cannot make its own food. Thus, for its first growth from the seed the young bean plant is entirely dependent on the nourishment stored in its two fleshy seed leaves.

Lying at the side of the two seed leaves and attached to them both is the first root of the plantlet. Notice how its tip lies just within the hole in the seed coat, ready, as it were, to come out from the seed at the first opportunity. (*Cf.* Figs. 7-10.) So far we have found a root and two swollen leaves in the seed. If we separate the leaves from each other we shall see the first bud of the plant. (Fig. 11.) The small leaves which here clothe the tip of the tiny stem can be dissected away with a needle. A hand lens, however, reveals their true beauty, for by its use we can follow the delicate tracery of the veins and realise that these are perfect leaves in miniature. The bean seed thus contains an entire plant composed of root, bud, and seed leaves. The only peculiarity, apart from the small size of the plant, is the relatively great size and unleaflike appearance of the two seed leaves. Considerations of dispersal (*see Chapter XVI.*) and nutrition will explain both the small size of the plant as a whole and the large size of the seed leaves.

10.

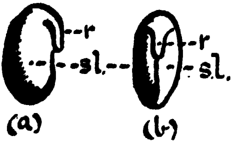


Fig. 10.—Bean Seed with Coat removed.—(*a*) Side view; (*b*) End view.

11.

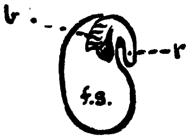


Fig. 11.—View of the Flat Surface (f.s.) *of one of the Seed Leaves after the other one has been removed.*—(*b.*)Bud; (*r.*)Root.

SUMMARY.

MATURE PLANT.

A.	Roots	(*a*) Absorb raw materials. (*b*) Anchor the plant.	Nutritive or Vegetative organs (concerned at first with life of present individual).
	Stems	(*a*) Conduct raw material to leaves. (*b*) Spread out leaves to light.	
	Leaves	(*a*) Make food.	
B.	Flowers:—	Produce fruits and seeds.	Reproductive organs (concerned with future individual).
	Fruits:—	Are the seed cases.	
	Seeds:—	Contain the next generation of plants.	

THE SEEDLING. Notice its small size, few leaves and roots, single stem.

THE SEED. Notice its protective coat and its contained plantlet.

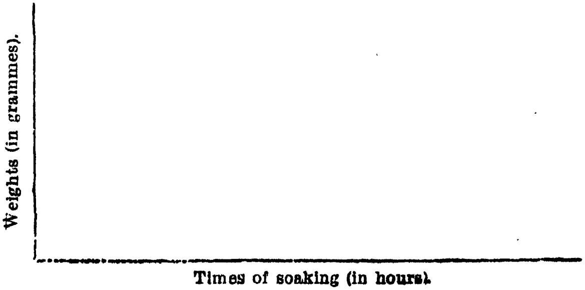
Plantlet. (i.) Root.
(ii.) Bud.
(iii.) Two swollen seed-leaves packed with food.

PRACTICAL.

1. Weigh a handful of beans—allow to soak twenty-four hours—dry on blotting paper. Find increase in weight per cent.

2. Is this percentage increase the same for other seeds? (Pea, lupin, sunflower, maize).

3. Is the increase at a uniform rate?
   Dry and weigh the peas at intervals of two hours.
   Is there any variation in the rate of increase? If so, can you explain the variation?
   Plot your results on a curve thus:



* * *

CHAPTER II.

Structure of Seeds.

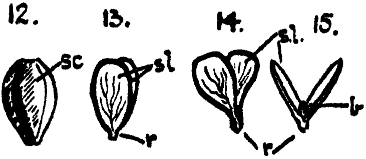
1. Seeds with Two Seed Leaves.

(*a*) PEA.—This differs from the runner bean only in its shape.

(*b*) BROAD BEAN.—This shows seed coat, scar, hole, root, seed leaves and bud more plainly than either the runner bean or the pea.

(*c*) LABURNUM.—This seed agrees entirely with both the above in structure.

(*d*) VEGETABLE MARROW.—(Figs. 12-15.) Here a broad flat seed coat covers the seed. (Fig. 12.) On this being removed, it is seen that the two seed leaves lie against each other throughout the length of the seed and also that they are joined to the root at their base. (Fig. 13.)

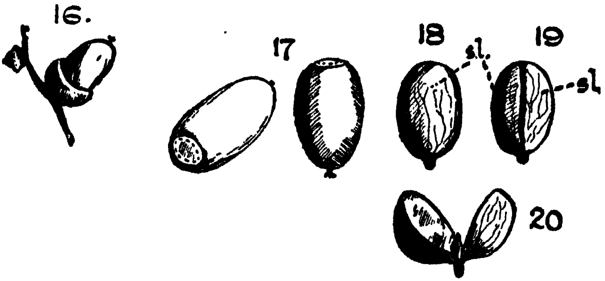


VEGETABLE MARROW SEED (*Figs. 12—15*).

Fig. 12.—Complete Seed.
Fig. 13.—Seed Coat (s.c.) *removed. Root* (r.).
Fig. 14.—Seed Leaves (s.l.) *separated.*
Fig. 15.—Same in end view to show the Bud (b.) *between the Seed Leaves.*

If we force the two seed leaves slightly apart we shall find the first bud enclosed between them. (Figs. 14-15.) The three following examples are fruits, not seeds. This means that the seed here is covered by two coats: one is the seed coat proper, the other is the fruit coat or seed vessel. This is precisely similar to a bean pod containing only one bean seed.

(*e*) **Acorn.**—(Figs. 16-20.) This has a woody glossy fruit coat. At the base of this is the scar where the fruit was attached to the cup. A circle of dots (Fig. 17) found in the scar marks the points of passage of the conducting strands, which supplied the developing acorn with food.



The Acorn (*Figs. 16—20*).

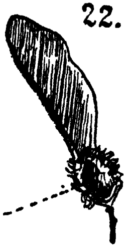
Fig. 16.—An Acorn.
Fig. 17.—The Cup removed, showing the Scar.
Fig. 18.—Shows the Plantlet covered by the Seed Coat.
Fig. 19.—End view of the Plantlet.
Fig. 20.—The Bud, Root and two Seed Leaves.

The tip of the acorn bears a projection, the three radiating regions of which represent the stigmas of the flower. After removing the fruit coat the kernel is found to be covered by a brown investment which adheres very closely to it. This is the seed coat proper, and within it is the oak plantlet. (Figs. 18-20.) The first root is seen with its tip nearest the stigmas of the fruit coat. The two seed leaves, forming the bulk of the plant, have the first bud lying between them. (Fig. 20.)

(*f*) **Sycamore.**—(Figs. 21-25.) This is another one-seeded fruit. It is an interesting fruit to study, because the seed is provided with a blanket of hairs to prevent injury by cold. These silky hairs form a padding between the seed coat and the fruit coat; in reality they are the innermost region of the brown woody seed vessel. (Fig. 22.) The seed coat is a thin reddish brown papery layer investing the seed within, yet quite distinct from the hairs. A small projecting ridge on the seed coat marks the position of the root lying inside. (Fig. 23.) The seed itself is a good example of the wonderful way space

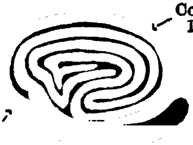
21.

22.

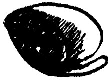


23.

25.



24.

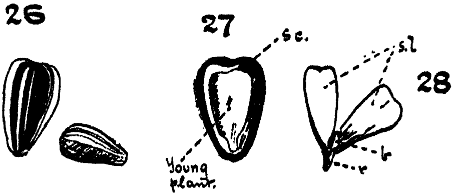


SYCAMORE (*Figs.* 21—25).

Fig. 21.—Double Fruit.
Fig. 22.—Half the Fruit Wall broken away to show the seed's hairy protection.
Fig. 23.—The Seed covered by a brown smooth Seed Coat.
Fig. 24.—The Seed with its Seed Coat removed. Note the root and the coiled seed leaves.
Fig. 25.—Arrangement of Root, Bud and Seed Leaves as shown by cutting the Seed lengthways.

is utilised in seeds. (Fig. 24.) The root is easily recognised, but at first sight all the rest of the seed seems a confused mass. With care, however, the two seed leaves can be unfolded. They lie parallel to one another in a close spiral, between whose coils there is no space lost whatever. (Figs. 24, 25.)

(*g*) SUNFLOWER.—(Figs. 26-28.) This fruit is a much simpler one than that of Sycamore. The fruit wall is hard, woody, and frequently marked with alternating dark and light bands. Inside, a thin white layer resembling tissue paper represents the seed coat and encloses the seed. The structure of the latter (Fig. 28) strongly recalls the plantlet of vegetable marrow or oak.

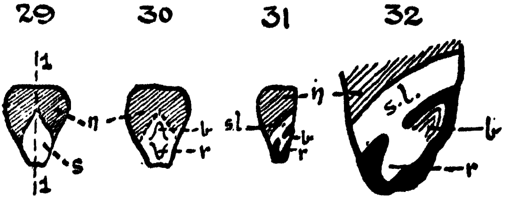


SUNFLOWER FRUIT (*Figs. 26—28*).

Fig. 26.—Complete Fruits covered with striped Fruit Coat.
Fig. 27.—One side of Fruit Coat cut away to show Plantlet within.
Fig. 28.—The Plantlet exposing its parts.—(*s.l.*) Seed Leaves; (*b.*) bud; (*r.*) Root.

2. **Seeds with one Seed Leaf.**—Here also it will be more convenient to examine fruits instead of seeds, since maize and wheat grains, which are fruits, are so readily obtainable. In these two fruits the fruit coat and the seed coat are fused and consequently are indistinguishable from each other. Together they form a hard rind to the grain. In the seeds hitherto studied, the young plants have completely filled the seed, the requisite nourishment being stored up in the seed leaves. We now come to a totally different type, in which the young plant occupies but a small part of the grain. Its seed leaf (for it has but one) is not a bulky storehouse of food. The food which caused the massive structure of former seed leaves is here deposited in the seed *outside the plantlet.*

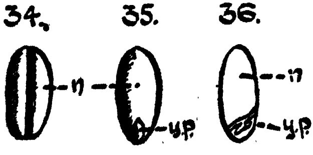
(*a*) MAIZE.—(Figs. 29-32.) One flat side of a maize grain is marked by a large white patch (Fig. 29); this shows the position occupied by the contained plantlet. All the remaining surface of the grain is a golden yellow colour, and under this lies the nourishment mentioned in the preceding paragraph. If the surface of the white patch be removed with a needle or sharp penknife, two small conical projections can be discovered. (Fig. 30.) The upper one is the bud, the lower the root of the maize plantlet. Both bud and root are attached to a white oval region lying internally to them. In this book we shall regard this region as the seed leaf, although it is only fair to say that some biologists regard it as *a part* only of that organ. We cannot tell how far this seed leaf proceeds into the grain unless we cut the latter lengthways. This we will do with a fresh grain (Fig. 31), cutting in the direction indicated by the line 1—1 in Fig. 29. The appearance of the cut surface is shown in Fig. 31. From this we see that the seed leaf is merely a flat plate. On its upper side is the white floury food stored up for future use; on its lower side is the remainder of the plantlet (bud and root) which we saw in our first specimen.



STRUCTURE OF A MAIZE GRAIN (*Figs. 29—32*).
Fig. 29.—Broad view of a Grain.
Fig. 30.—Sheath has been removed along dotted line.
Fig. 31.—Section along the line 1—1 in Fig. 29.
Fig. 32.—Lower part of Fig. 31 magnified.

The seed leaf is admirably situated for the performance of its work, which comprises (i.) the digestion of the stored food, and (ii.) its transference in soluble form to the plantlet lying on its outer side. The bud of the plantlet will repay dissection (Fig. 32), for by means of a needle we can raise up several leaves.

(*b*) WHEAT.—(Figs. 34-36.) The wheat grain has a much smaller plantlet than maize. The position of this can readily be seen from Figs. 34 and 35, which show the two surface views of the grain. The plantlet is so small that very little detail of structure can be made out by the naked eye. The general position of the plant and its nourishment is indicated in Fig. 36, but Fig. 32 on the maize grain will represent wheat equally



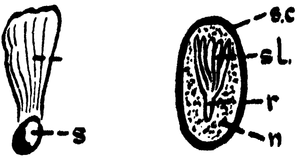
STRUCTURE OF A WHEAT GRAIN (*Figs. 34—36*).
Fig. 34.—Front view.
Fig. 35.—Back view.
Fig. 36.—Cut lengthways.—(*y.p.*) Young plant; (*n.*) nourishment.

well. The main points to be remembered about these fruits are :—

1. The fusion of the two coats.
2. The one seed leaf present.
3. The nourishment stored up outside the plantlet.

3. **A Seed with many Seed Leaves. Pine.**—(Figs. 37, 38.) The vast majority of green plants provide their plantlets with either one or two seed leaves. Pine is an exception; it has ten or more seed leaves to its young plant. Externally, the seed coat is prolonged into a brown membranous wing to aid in dispersal by the wind. The woody seed coat encloses much nutriment in addition to the young plant. The relative positions of the plant, nourishment and seed coat are shown in Fig. 38.

37. 38.



STRUCTURE OF PINE SEED (*Figs. 37—38*).

Fig. 37.—Entire Seed and Membranous wing.

Fig. 38.—Seed cut lengthways.—(*w.*) Wing; (*s.*) Seed; (*s.c.*) Seed Coat; (*s.l.*) Seed Leaves; (*r.*) Root; (*n.*) Nutriment.

SUMMARY.

STRUCTURE OF SEEDS.

1. **With two Seed Leaves.**
   - (*a*) Pea, broad bean, and laburnum seeds greatly resemble that of scarlet runner bean.
   - (*b*) Vegetable marrow, oak and sunflower seeds have the first root lying at one end of the seed.
   - (*c*) Sycamore seed has a woolly fruit coat. Its two seed leaves are coiled into a spiral.

2. **With one Seed Leaf.**

   Nourishment is not stored up in the plantlet itself. The plantlet is much smaller than those of the above plants. In maize and wheat the single seed leaf occupies a position intermediate between the plant and its food. The seed leaf renders the food soluble and transmits it to the plant.

   The seed and fruit coats are fused in maize and wheat grains.

3. **With many Seed Leaves.**

   Pine seed is winged externally. This aids dispersal by wind.

   The plantlet (root, bud, and many seed leaves) is embedded in nourishment.

PRACTICAL.

Soak and dissect as many seeds as possible.

Make drawings and name all the parts shown.

CHAPTER III.

Conditions of Germination.

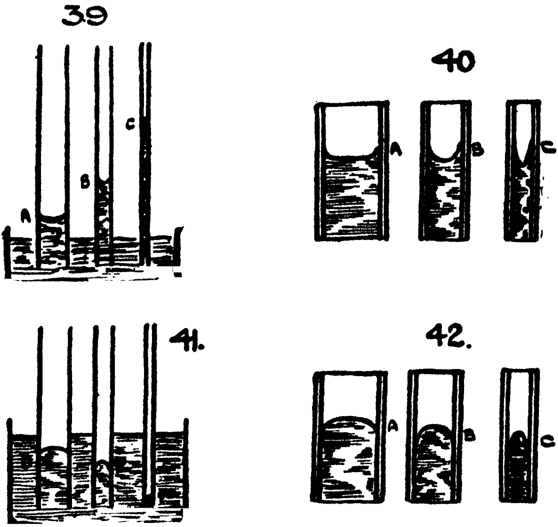
I.—THE SEED IN RELATION TO WATER AND AIR.

1. **The Penetrating Power of Water.**—When we contrast the horny texture of the unsoaked seed with its soft yielding nature after being soaked, we cannot but feel surprised that so great a change has been effected in so short a time. Water possesses a great penetrating power, and the strange part about this is the facility with which it oozes through exceedingly small spaces. In fact, we may say with truth that the smaller the spaces, the more easily will the liquid pass into them in some cases.

2. **Capillarity.**—If a number of open glass tubes of various diameters be immersed in a vessel of water (Fig. 39) it will be found that the liquid rises up all the tubes against the force of gravity. The narrower the tube, the greater is the height to which the water will rise. On the other hand, if we immerse the tubes in a vessel of mercury instead of water, we shall find that in all of them the mercury stands at a lower level than that in the vessel, and is depressed most in the tube which has the smallest bore. (Fig. 41.) A clue to the causes of the varying behaviour of mercury and water in the tubes is given by an examination of the tips of the columns. (Figs. 40-42.) The upper ends of the water columns in tubes *A*, *B*, *C* (Fig. 40) are curved. These curves vary with the bore of the tube, being most pronounced in the finest tubes.

A simple explanation (although the whole question belongs to Mathematics) is that the water wets the glass, creeps up the sides of the tube, and drags up the column of water with it. This lifting power is relatively greater in the smallest tubes.

The tips of the mercury columns are curved in the opposite direction. (Fig. 42.) The reason is that mercury does not wet the glass; it thus tends to be kept back around the sides of the tube and the whole column is consequently depressed. On removing the tubes from the water or mercury, another valuable fact is manifest: some of the liquid remains in the tubes. The same thing is noticed when a fluid is admitted between opposed surfaces of glass, held so as to be almost touching. When dipped into water the fluid will rise between the plates of glass to a height depending upon the proximity of the surfaces to each other. Lump sugar and blotting paper, when dipped into water, furnish familiar examples of the same force. This attraction of water into small spaces whose sides can be wetted is termed Capillarity. The above principle has important bearings both on seed and soil.



Figs. 39—42.—Diagrammatic view of the effect of Capillarity in Tubes of different bore.—In Figs. 39 and 40 the liquid is water. In Figs 41 and 42 it is mercury.

3. **Capillarity in the Soil.**—We know that soil is porous and will hold water, because we can water a plant growing in a pot for a few moments before the liquid runs out from the bottom. We may regard the soil as a mass of particles with air spaces between them. These air spaces, in a sense, may be likened to the glass tubes of our experiments. Clearly the tendency will be for these tiny spaces to retain some of the water which percolates downwards through them from the air above.

4. **Capillarity in the Seed.**—Will there be any similar process going on in the bean itself? The answer to this question of course depends on the presence or absence of air spaces in the bean. The microscope enables us to see that the whole structure of the seed (as also other parts of plants) is honeycombed with a ramifying system of air spaces. (Fig. 43.) The universal provision of these emphasises how essential an adequate supply of oxygen is to the plant. We may look on these spaces as the "lungs" of the bean seed. From their exceedingly small size they will very readily suck in the water from the soil.

43

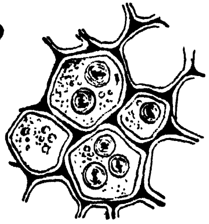


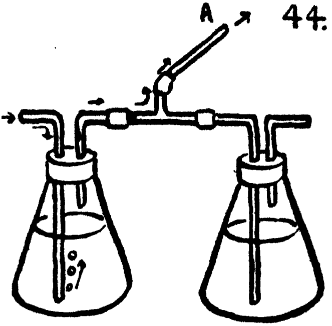
Fig. 43.—A very small part of a Bean Seed magnified 75 times.—The black parts are air spaces. These lie between the living chambers of the Seed.

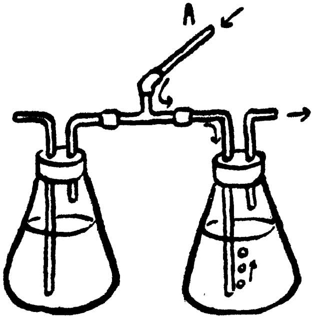
When water fills the spaces in the bean seed it displaces the air from them. If this were a permanent condition it would be very harmful to the seed, in fact it would absolutely prevent growth by depriving the plantlet of the oxygen it requires for breathing purposes. Seeds cannot grow into plants if they are left at the bottom of a vessel of water where they are deprived of oxygen.

5. **Diffusion in the Seed.**—The water does not stay in the air spaces. It permeates right through the bounding walls of these into the living cells or chambers lying beyond, and there it forms a larger amount of sap than was present in the dry state of the seed. Thus every living part of the bean is becoming swollen out with more sap during the soaking process. The sum total of all these individual increases is expressed outwardly by the fact that the soaked bean is larger than the dry one. The power which water possesses of rapidly soaking through different materials is termed its diffusibility. It is by virtue of this that it ever reaches the true living parts of the seed at all. Fig. 43 will make clear the distinction between the air spaces and the living chambers of the bean.

AIR AND THE SEED.

6. Composition of the Air from a Respiratory Point of View.—We all know that without air we should soon die, and that breathing is necessary for life. By alternately breathing in and out through the tube *A* of the apparatus shown in Figs. 44 and 45, we can see that air undergoes a change in composition whilst inside the body. A person using this apparatus causes a current of air to travel through the left-hand bottle and tubes during inspiration (Fig. 44), and through the right-hand bottle during expiration. (Fig. 45.)





45

The Arrows in Fig. 44 show the path taken by the air during inspiration.
Those in Fig. 45 show the path during expiration.

This contrivance is specially useful because by it we can compare the composition of the same air before entering and after leaving the body. Both the bottles are half-filled with lime water.

This liquid always indicates the presence of carbonic acid gas by becoming milky, for carbonic acid gas combines with the lime in the water, producing tiny particles of chalk. These, suspended in the water, give it its cloudy appearance or milkiness. In performing the experiment, the operator breathes solely through the tube *A* for a minute or so. The left-hand bottle remains quite clear or is only clouded very slightly, whereas the liquid in the right-hand bottle becomes very milky.

It is clear that a large amount of carbonic acid gas has been added to the air whilst inside the body. Yet if the volumes of air entering and leaving the body be carefully measured they will be found to be as nearly as possible identical in amount. This carbonic acid gas must therefore have replaced some other constituent of the air. What is this constituent?

If a candle be burnt in a limited supply of air (Fig. 46) it will very soon be extinguished, and very much carbonic acid gas will be found in the jar, for a little lime water shaken up in the jar will become very milky.

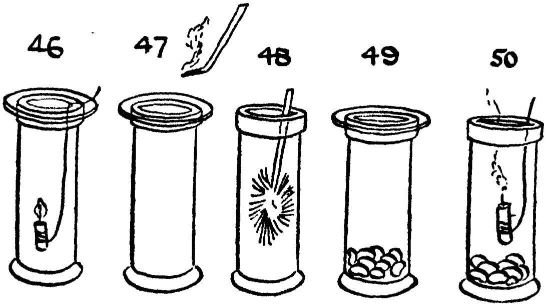


Fig. 46.—Candle burning for a short time in a limited supply of air.
Fig. 47.—A smouldering splint ready for plunging into oxygen gas.
Fig. 48.—The brilliant flame produced when it is plunged into oxygen gas.
Fig. 49.—Beans germinating in a limited supply of air.
Fig. 50.—After a few days a candle will not burn in the jar.

The candle only burns in the jar until it has used up the oxygen of the air, and this is the constituent which the carbonic acid gas has displaced. Pure oxygen supports burning very vigorously indeed. A glowing splinter of wood bursts into flame when immersed in this gas (Figs. 47, 48), and after it has burnt out, the jar will be found to contain very much carbonic acid gas.

In the air then we have oxygen gas by means of which combustion can be carried on, whilst from this combustion carbonic acid gas is produced. Normally air contains about ⅕ of its volume of oxygen and a very small amount, about ·03%, of carbonic acid gas.

7. **True Nature of Respiration.**—The fact that air leaving the human body contains more carbonic acid gas and less oxygen than it did on its entrance suggests very strongly that there is a "burning" process going on in the system. This actually is the case; the body is always wearing away or

decomposing, and the strangest part of the whole process is that protoplasm can only preserve its living condition by dying (or decomposing) continuously.

This decomposing or burning process constitutes true respiration, and the latter word will be used here in this sense and not in its popular meaning of breathing air in and out from the lungs.

8. **Do Seeds Respire?**—This question must be understood to mean:—"Do seeds burn up their contained organic materials?" and if the answer is in the affirmative, it will be well to ask these further questions:—

(*a*) Is oxygen necessary for growing seeds?

(*b*) Does respiration in seeds produce heat as it does in our own bodies?

(*c*) Is it fair to assume that respiration in seeds is the same process as in animals?

EXPERIMENT 1.—A dozen soaked beans are placed in a gas jar, covered with a glass plate, and left for a day or so (Fig. 49.) A lighted candle is extinguished when it is lowered into the jar at the end of this time (Fig. 50.) From this we infer that oxygen has been removed from the air by the beans.

EXPERIMENT 2.—A wash bottle containing soaked beans (*A*) is fitted up to two wash bottles of lime water (*B*, *C*). Air is caused to slowly traverse the whole series of bottles by the gradual emptying of the water from the aspirator (*D*). The air on entering at (*E*) bubbles through the lime water in (*B*), is

51.

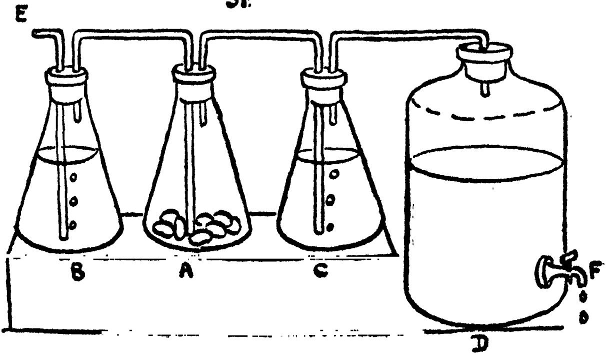


Fig. 6.—Apparatus to prove that germinating Seeds respire.

carried into the midst of the beans in (*A*), bubbles through the lime water in (*C*) and finally occupies the aspirator (*D*), the water from which is gradually escaping by the tap (*F*). The lime water in (*B*) remains clear; that in (*C*) is very milky. Seeds therefore produce carbonic acid gas. Since they, being living things, use up oxygen and give out carbonic acid gas, we are justified in saying that they respire.

9. **Is Oxygen necessary for the Seed's Respiration?**—Although soaked seeds can grow for some time in complete absence of oxygen, they cannot develop to any great extent without it. Sooner or later oxygen becomes an absolute necessity, for without it the plantlets die.

10. **Is Heat Produced by the Respiration of a Seed?**—A thermometer is immersed in soaked seeds (*A*, Fig. 53) and another to an equal depth in dry ones (*B*, Fig. 53), the whole being covered by a glass shade. The following table gives the readings obtained:—

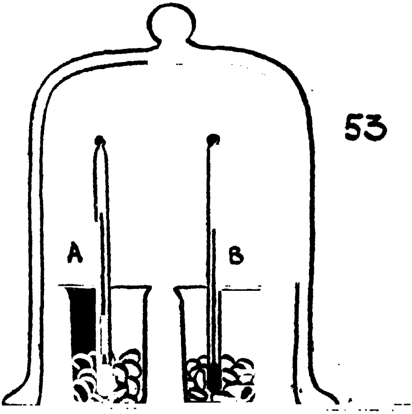
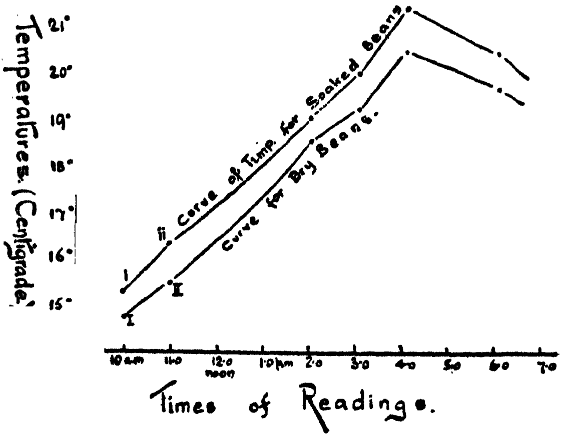


Fig. 53.—The Thermometer A placed in soaked germinating Beans shows a higher temperature than B placed in dry Beans.

TIME.	"*A*" READING.	"*B*" READING.
10 a.m.	15·3°	14·8°
11 a.m.	16·3°	15·5°
2 p.m.	19°	18·5°
3 p.m.	20°	19·2°
4 p.m.	21·5°	20·5°
6 p.m.	20·5°	19·7°

These results are best shown by a curve which is obtained as follows :—A dot is placed opposite a "time" and its corresponding "temperature," as at the points I. i., which indicate the two temperatures at 10 a.m. and II. ii., which indicate the two temperatures at 11 a.m. The curves are obtained by joining up the points. The chief value of such curves here is that we can see all our results at a glance, and the curve given by the soaked beans shows that these were always at a slightly higher temperature than the dry ones. In other words, respiration was proceeding at a greater rate in the soaked seeds.



54.

Fig. 54.—Temperature Curves.—The height above the horizontal line indicates the temperature.

In dry seeds there is only just sufficient respiration going on to keep the plantlets alive.

(N.B. The temperature of the room gave a curve practically identical with the "dry bean" curve.)

The above experiment proves that respiration in seeds produces heat as it does in animals.

Summarising :—Seeds *do* respire. They resemble animals in their respiration in that

(i.) Oxygen is essential.
(ii.) Carbonic acid gas is evolved.
(iii.) Heat is produced by respiration.

Therefore, we are justified in regarding respiration as an identical process in plants and animals.

SUMMARY.

Water tends to remain in the soil by capillarity.

It enters into the air spaces of the seed by capillarity, but into the living cells of the plant by diffusion.

The atmosphere supplies oxygen for breathing, and carbonic acid gas is produced by this process.

Breathing consists of a decomposing process in all parts of a creature's system.

Seeds respire in a similar way to animals; they require oxygen; they produce carbonic acid gas; heat is evolved during the process.

PRACTICAL.

1. Test how long various seeds take to become completely soaked. (This can be found by weighing from time to time).
2. Perform all the experiments described in the text.

   In the experiments where beans are used, try other seeds.

Wherever possible plot a curve showing your results.

3. Take two sets of bean seeds. Close the small holes (*or micropyles*) of one set with sealing wax or plasticine. Weigh the two sets; then soak, wipe dry, and weigh at intervals. From your results compare the amounts of water which enter by (*a*) the micropyles and (*b*) the general surfaces of the seed coats.

CHAPTER IV.

Conditions of Germination.

II.—GROUND AIR AND MOISTURE.

1. **The Ground Air—its Presence and Amount.** EXPERIMENT.—A gas jar (any other vessel will serve) has its capacity ascertained by filling it with water from a graduated measuring glass. It is emptied, dried, and then filled with soil. Water is then poured in until it just appears at the level of the soil. The volume of water required gives us the volume of the air which was contained in the interstices of the soil and which has been expelled by the water. In an experiment 385 ccs. of soil took up 180 ccs. of water. When a gardener thoroughly breaks up the soil previous to planting his seeds, he is really ensuring that they (and also the young plants whilst still underground), shall receive a sufficient supply of air.

2. **Composition of the Ground Air.**—The outdoor atmospheric air remains remarkably uniform in composition. Have you ever thought why this is so? All gases have the power of diffusing or mingling with each other. If gaseous impurities are given out into the air they tend to spread through an ever increasing aerial region.

The carbonic acid gas we give off in breathing does not remain in our immediate neighbourhood. It diffuses to those parts of the air where there is less of this gas. Similarly, the air close to us tends to become impoverished in oxygen because we are continuously using some of this gas in breathing. But other oxygen passes towards us from regions containing more of it. The various gases of inhabited air are constantly in movement, with the result that approximately they are found in constant proportions. In the same way a seed germinating in the ground will have a slight current of oxygen towards it and of carbonic acid gas away from it. We cannot, however, regard the ground air as of the same composition as the atmosphere itself. In the soil much decomposition of dead animal and vegetable substances is always taking place. Since such decomposition requires oxygen and liberates carbonic acid gas, we find that the ground air contains less and less oxygen with more carbonic acid gas, as it proceeds further into the soil.

What then is the position of a seed in the ground with respect to this oxygen gas, which is so vitally necessary for its breathing processes?

(*a*) It has relatively little air, for the air only occupies the *spaces* between the soil particles.

(*b*) This air is poor in oxygen.

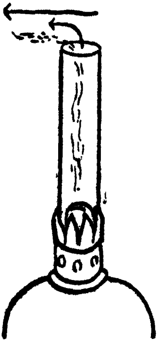
(*c*) The deeper the seed is sown, the worse becomes its supply of oxygen.

This last, together with other considerations discussed later, helps to explain why seeds do not grow when sown too deeply.

The student should guard against the erroneous idea that the sole currents in the ground air are those mentioned above. These diffusion currents are very slight indeed compared with the larger movements of the ground air.

3. **Movements of the Ground Air as a whole.**—Let us consider these latter movements a little more in detail and the factors which produce them. Bear in mind that we are dealing here with movements of the ground air as a whole. What has been said above referred to diffusive movements of certain constituents (oxygen and carbonic acid gas) of the ground air.

(1) EFFECT OF THE WIND.—If a person blows strongly across the top of a lamp chimney, the light is extinguished. The reason for this is that the cross current of air over the top of the glass causes a strong upward current in the chimney (Fig. 55.) Consider now the effect of the wind blowing across the land; think with what force it sweeps over the soil of exposed fields. We can at once see that it will



55

Fig. 55.—A current of air across the top of a lamp causes an updraught and puts out the light.

have a very strong effect in sucking out the ground air from the air spaces of the soil.

(2) **Effect of Barometric Pressure. Principle of the Barometer.**—The barometer is one of the easiest instruments to understand. A large tube filled with mercury has its open mouth immersed in a vessel containing the same liquid. One would at first expect that the mercury would run out from the tube into the vessel. (Fig. 56.) This, however, does not occur. It does fall a few inches if the tube is a yard or so long, but we seldom find that it sinks more than this. The atmosphere presses downwards on the exposed mercury surface (as indicated by Fig. 56), and this pressure is sufficient to hold up the column of mercury in the tube. According as the pressure of the air on the mercury is greater or less, so we have a longer or shorter column of mercury supported in the tube. The height of the mercury column thus affords us a ready way of estimating the pressure of the atmosphere. This atmospheric pressure is subject to variation, although here it is not pertinent for us to enter into the causes of such.

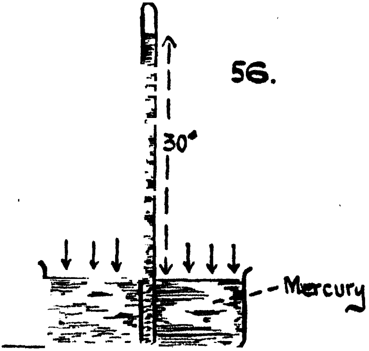


Fig. 56.—Principle of the Barometer.

The question for us is:—"How will variation in barometric pressure affect the ground air?" If the atmospheric pressure increases it tends to drive the ground air further into the soil. When it decreases some of the ground air comes out into the atmosphere.

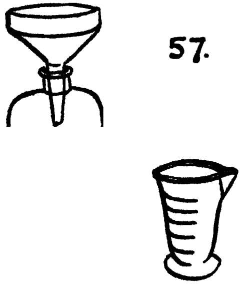
(3) **Effect of Temperature.**—The table of temperatures (Fig. 61) shows that the ground and the air above very rarely have the same temperature. Now the ground air has the same temperature as the ground itself; consequently, ground air and atmospheric air differ in temperature.

An easy experiment will show that air expands when its temperature is raised:—If a balloon half filled with air be placed in front of the fire, it will speedily swell to its full size. We will apply this principle to the temperatures of the ground air and the atmosphere. Suppose the ground air becomes warmer than the atmosphere, the former will expand and some of it will escape from the ground into the air above. Whenever the opposite is the case, the expanding atmosphere forces its way some distance into the soil.

(4) Effect of Heavy Rain.—A heavy rain storm drives the ground air before it deeper and deeper into the earth. The combined effects of these four factors is that the ground air is in a state of constant ebb and flow. We may say that there is always one or other of the two processes going on—either ground air escaping from the ground, or atmospheric air entering the ground.

4. **Effect of Ground Air Movements on Seeds Underground.**—Will this ebbing and flowing be beneficial or prejudicial to the germination of seeds below ground? We have already noticed that ground air contains less oxygen than the atmosphere. Any movement tending to replace the relatively foul ground-air by atmospheric air will aid seed growth, in that more oxygen will be provided for the breathing process. Briefly then, the underground seed has oxygen supplied to it (*a*) by gross movements of the ground air (consequent on wind, air pressure, air and soil temperature, and rain), (*b*) by delicate diffusive currents (carrying oxygen to it, and carbonic acid gas away from it).

5. **Necessity of Rain—The Rain Gauge.**—It seems superfluous to mention that a sufficient supply of rain is an absolute necessity for germination, but it is very instructive to keep a record of the amount of daily rainfall as measured by the rain gauge and to note how responsive vegetation is to this rainfall. In particular, records should be kept of the rainfall during several successive Spring seasons and the dates of appearance of plants above ground should be noted alongside. A very close connection indeed will be found between the phenomena. A simple home-made rain gauge is shown in



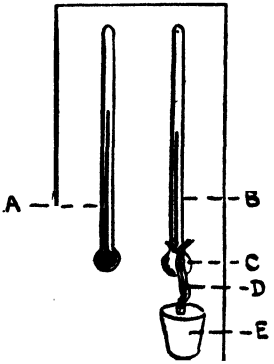
57.

Fig. 57.—A Home-made Rain Gauge.

Fig. 57 (it merely consists of a funnel, glass bottle, and measuring vessel). If it be desired to calculate the amount of rainfall in inches, the following formula will give the required result:—

If a volume of x ccs. of rain be collected by a funnel of y cms. diameter, the rainfall in inches $= \frac{1}{2} \times \frac{x}{y^2}$ (approximately). Example:—Suppose 40 ccs. rain are collected by a funnel 10 cms. diameter the rainfall is $\frac{1}{2} \times \frac{40}{100} = \frac{1}{5} =$ ·2 inches.

6. **Effect of Amount of Moisture in the Atmosphere.**—One further point naturally calls for consideration here, *i.e.* the effect of the humidity of the atmosphere on the soil. The atmosphere contains a varying amount of water vapour. The drier the air at any particular temperature the more the water will tend to pass into it from the soil below. If the air be relatively poor in water vapour, evaporation will be induced from any exposed moist surface. This fact is utilised in Mason's wet and dry bulb thermometers. (Fig. 58.)



58.

Fig. 58.—The wet and dry Bulb Thermometers.

One thermometer (a) is exposed to the air in normal fashion. The other (b) has its bulb covered with muslin, (c) from which proceeds a twisted muslin strand (d) into a covered vessel of water (e). The muslin (c) is kept continually moist by water which rises by capillarity through (d). According to the dry or moist state of the atmosphere, there is more or less evaporation from (c) the muslin bag. But when water evaporates it produces cold; therefore the thermometer (b) will give a lower reading than (a). If much or little evaporation is going on from (c) there will be a corresponding difference between the readings of the two thermometers. Since the surface of the ground is a moist surface, we can regard the difference between the thermometer readings as a *rough* indication of the rate at which the soil is drying.

7. **Temperature and the Seed.**—Before entering on this section in any detail, let us briefly note the effect of various temperatures on our own bodies. We know that

both extreme cold and heat prevent us from working well, yet there is a temperature somewhere between these limits at which we can work normally. So it is on the plant side of life. For every kind of work that the plant has to perform—whether it be absorbing, making food or growing—there are limiting temperatures (minimum and maximum) between which the particular work can be performed, and there is also *the optimum or ideal temperature at which the activity of the plant is most manifest.*

As a general rule we may take 0° C. and 50° C. as the minimum and maximum temperatures, and about 30° C. as the optimum temperature for plant activity. Fig. 59 represents this activity in the form of a curve, where height above the base line represents how active the plant is at any particular temperature. To make the above more tangible to the student's mind, let us take a definite example. Wheat grains begin to germinate at a minimum temperature of 5° C., they germinate best at 29° C., whilst 42° C. is the highest temperature at which they can germinate.

59

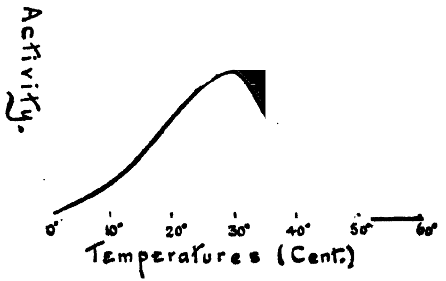


Fig. 59.—Curve of Activity.—The height of the curve (at any point) from the horizontal line denotes the amount of activity displayed at that temperature.

Also, as with ourselves, some people "feel the cold" and other conditions of temperature more keenly than others (*i.e.* individual people respond in different degrees to temperature stimuli), so amongst plants we find this same individuality of behaviour; since plants as well as animals possess characteristic inherent peculiarities.

Compare the following with the temperatures given above for wheat:—Maize begins to germinate at 10° C. (minimum), it germinates best at 34° C. (optimum), it refuses to germinate at a temperature above 46° C. (maximum). Fig. 60 compares the behaviour of the two plants.

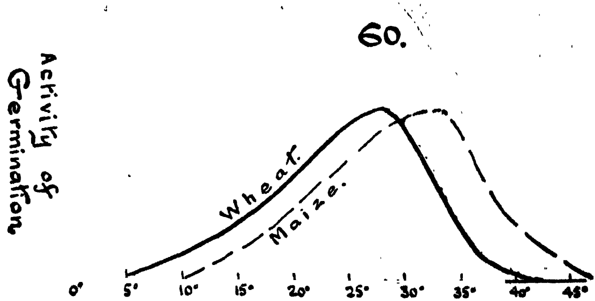


Fig. 60.—Curves of activity of Germination of Wheat and Maize.
N.B.—The "individuality" of the plants.

Temperature therefore exerts a very vital, essential influence on plants, for unless the minimum temperature be present plants can neither germinate nor mature. Also the nearer the temperature approaches the optimum the more vigorously will the plant perform any particular function. Since this question of temperature is such an important one, the results of two experiments investigating temperature conditions are given here in full.

8. **Temperature of the Soil and the Air above.**—EXPERIMENT 1.—To investigate the relations existing between the temperatures of (*a*) the air, (*b*) the soil; at:—

(i.) 3″ }
(ii.) 6″ } depth from the surface.
(iii.) 9″ }
(iv.) 12″ }

The Table and curve (Fig. 61) give the results obtained by hourly readings from 8 a.m. to 6 p.m., one October day.

TIME.	TEMPERATURES.				
	AIR.	SOIL.			
		i.	ii.	iii.	iv.
8 a.m.	9	9·2	10	10·3	12
9 „	10·8	9·8	10	10·3	12
10 „	13·3	10·6	10·3	10·4	12
11 „	14·3	12	10·5	10·4	12
12 noon	15	11·5	11	10·5	12
1 p.m.	15·4	12	11	10·6	12
2 „	15·4	12·2	11·3	10·7	12
3 „	15·5	12·5	11·7	11	12
4 „	15	12·5	11·8	11	12
5 „	14	12·5	11·8	11	12
6 „	13·1	12·4	11·8	11	12

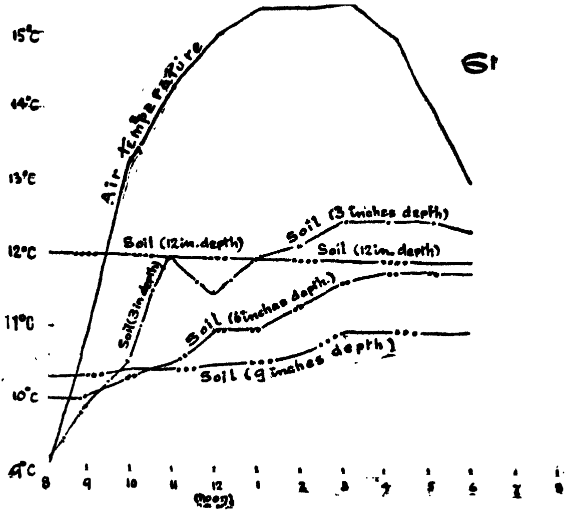


Fig. 61.—Curves of temperatures of air and soil.—The readings were taken on a dull October day with no sun.

We note from the above that:—

1. The air above fluctuates much more in temperature than the soil below.
2. The air is colder than the soil at night and early morning, but warmer than the soil during the day.
3. The surface region of the soil fluctuates more in temperature than the deeper regions.
4. The soil at 12 inches depth preserves a uniform temperature, thus showing it is unaffected by the air temperature.

If the experiment had been continued through the evening and night, the curve of air temperature would have sunk lower than those of the soil.

EXPERIMENT 2.—To investigate the variation in temperature in different parts of the same district on a rather dull day with a warm southern wind.

SITUATION.	TEMPERATURE.	REMARKS.
A. On a hill top.		
1. Exposed to sun and wind	18°C.	
2. 3 inches deep in soil at same spot ..	14·9°C.	Soil colder than the air above.
3. Windy, shady side of a hawthorn bush	15·5°C.	The wind was a heating agent here.
4. The same on the side sheltered from the wind	14 1°C.	
5. The water of a pond with the sun on it	14·2°C.	Sun's effect.
6. The water in another part of the pond with no sun on it	13·7°C.	

SITUATION.	TEMPERATURE.	REMARKS.
B. In a wood (a natural hollow with oaks and hornbeams).		
1. Sunny position, no wind	15·5°C.	Effect of absence of warm wind.
2. In shade with no wind	14·5°C	Effect of absence of sun.
3. Bulb buried in the dead leaves lying on the ground	12°C.	How dead leaves keep the ground warm.
4. 3 inches deep in the soil below.. ..	12·2°C.	
5. 3 inches deep in the soil, not covered by dead leaves	12°C.	
6. The water of a shallow pool	12·3°C.	How moisture makes a soil cold. (Contrast A2 and B4 with B7).
7. 3 inches deep in the mud of the same	11·8°C.	

The student should investigate for himself the temperatures of a small piece of ground, such as a house garden. The variations found will be surprising; and the response by vegetation will be even more so. He is also strongly advised to collect climatic data for himself over a period of several seasons. The actual readings will only take a few minutes daily. He will then be able to judge of the intimate relation which exists between these physical conditions and the physiological responses they evoke from plant life, and particularly from germinating seeds. Some such form as that given in Appendix 1 will be found very useful for this purpose.

SUMMARY.

The ground air has more carbonic acid gas, less oxygen than the atmosphere. Its constant movement is due to

(*a*) Diffusion currents.

(*b*) Aspirating action of wind.

(*c*) Differences in temperature and pressure between ground air and the air above.

(*d*) Heavy rains.

These movements of the ground air tend to supply the seed with more oxygen.

Rain is necessary for supplying requisite moisture.

If the atmosphere is dry it dries the soil.

The performance of all the plant functions also depends on a suitable temperature.

The minimum and maximum temperatures give the extreme range of temperatures at which the plant can perform its work.

The optimum temperature is that at which the plant is most active.

Plants possess an individuality. The minimum, optimum and maximum temperatures differ slightly for different plants.

The temperature of the air differs widely in various parts of the same district.

The temperature of the soil must not be assumed to be the same as that of the air above.

PRACTICAL.

1. Test the amount of ground air contained in as many different kinds of soil as possible.
2. Test the rapidity with which chlorine or other strong smelling gas, will penetrate to every part of a room.
3. Examine the mechanism of a scent spray and explain its action.
4. Make a rain gauge.
5. Prove that evaporation produces cold (by allowing a little ether or alcohol to dry up in the palm of the hand).
6. Investigate temperature conditions when a *cold* wind is blowing.
7. Keep a record of climatic data on a form similar to that given in the appendix.

* * *

CHAPTER V.

Germination.

1. Germination Methods.—If we grow seeds in the ordinary way, in shallow boxes of soil, we experience two difficulties :—

(*a*) We cannot see what is going on below ground.

(*b*) The soil obscures the root system when taken up for examination.

Since most seeds contain sufficient nourishment in themselves to enable them to grow for a considerable time, we may obviate the second of these drawbacks by using damp sawdust or some other similar material. (Fig. 62.)

62

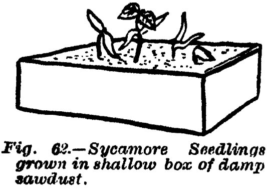


Fig. 62.—Sycamore Seedlings grown in shallow box of damp sawdust.

The first disadvantage is much more real, for if we cannot see the earlier stages of the germinating process we very often miss the most interesting part, *i.e.* how the seed is enabled to get out from its seed coat. There are two very good methods by which we can render all the initial stages visible to the eye :—

(*a*) We may utilise a lamp chimney, as shown in Fig. 63. The soaked seeds are pushed down between the glass and a roll of drawing paper. Within the paper we place damp moss, cork dust, sawdust or soil, so that with occasional watering the seeds have the necessary moisture.

(*b*) We may use a chalk-box for the purpose, running a glass plate into the groove in the sides of the box. (Figs. 64, 65.)

This will form the front of our "inspection chamber." One side of the box should be removed so that a paper sheet may be placed between the glass and the damp moss, etc., with which the box is filled. The seeds are pushed down between glass and moss as in the former methods.

By using either of these contrivances we have the whole process perfectly visible, and although we prevent the rootlets growing out in their natural directions, this is more than compensated for by our seeing the initial process of growth.

63

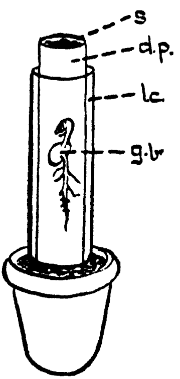
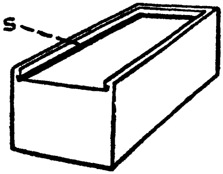


Fig. 63.—Germination of a Bean between a lamp chimney and a roll of paper. The cylinder of paper contains damp sawdust.—(Moss, cork-dust, or soil could also have been used.)

2. **Germination of Plants with two Seed Leaves.** — (*A*) The Runner Bean.—(Figs. 66-70.) The first thing noticeable in the germination of this seed is the splitting of the seed coat near the scar and the emergence of the first root. This root always behaves in the same way; it turns downwards as soon as it is free from the seed coat. Our later work will show us that the tip of the root is exceedingly sensitive to the stimulus of gravity, and that its downward growth is in

64



65

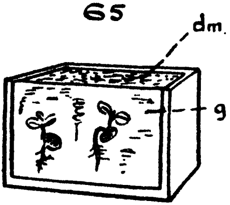
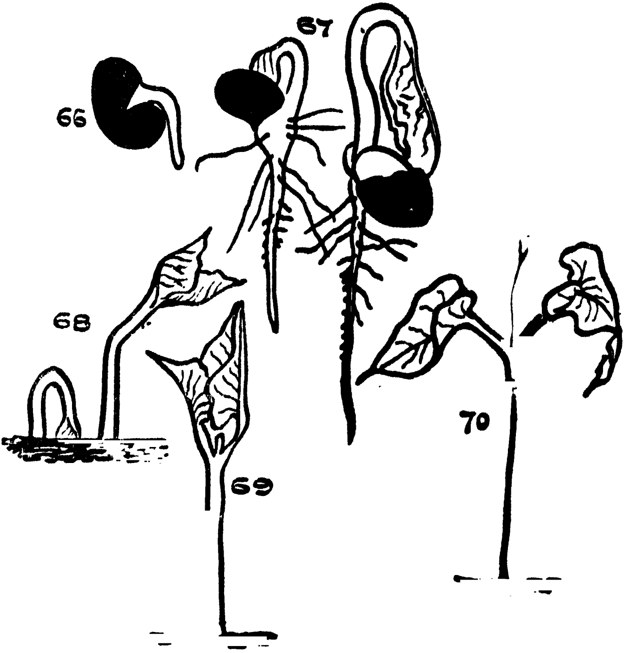


Fig. 64.—Chalk box showing slot into which glass front may be fixed.
Fig. 65.—The same fitted up as an "inspection chamber."—A sheet of paper is placed between the glass (*g.*) and the damp moss (*d.m.*)

direct response to this stimulation. The appearance of the root before the other parts of the young plant is an invariable rule; it is more—it is a physiological necessity, for the stems and leaves can never emerge from the seed until they have been supplied with water which the root has absorbed from



GERMINATION OF THE RUNNER BEAN (*Figs. 66—70*).

Fig. 66.—Root emerging.
Fig. 67.—Coiled or looped Stem dragging up the leaves after it.
Fig. 68.—Loop appearing above ground and straightening out.
Fig. 69.—Stem now straightened.
Fig. 70.—First foliage Leaves expanded and first Bud growing up between them.

the soil. When sufficient water has been absorbed the stem grows out from the seed in the form of a loop, the leaves as yet remaining within. The majority of plantlets force their way up through the ground in this looped condition. There are two very good reasons for this:—

(*a*) Since the delicate leaves are drawn up through the ground after it has already been pierced by the stem, they and the very frail bud enclosed by them are less liable to injury.

(*b*) Growth in length occurs in both arms of the loop, the plant thus obtaining a double thrusting power.

Notice how the looped stem gradually straightens itself out and brings the expanding foliage leaves well out to the light and air.

(*B*) MEASUREMENT OF THE LIFTING POWER EXERTED BY A GROWING BEAN PLANT.—(Fig. 71.) Two copper wire springs of equal strength were prepared from the same reel of wire. The lengths of these rather open springs were 15·4 cms. One spring A was loaded with increasing weights attached to a light collar and the lengths of the spring were carefully measured and plotted on a curve B. This curve B expresses the following results:—

LOAD.	LENGTH.	LOAD.	LENGTH.
0	15·4 cms.	40 gms.	13·7 cms.
20 gms.	14·7 „	80 „	11·6 „

The second spring was fitted (as in Fig. C) within a glass tube in such a way that it could be freely compressed by a young bean plant pushing upwards against a hollow cork. A centimetre scale fastened behind the tube enabled the length of the spring to be ascertained merely by reading the level of the top of the cork against the scale. The lengths so obtained were expressed in grammes pressure, merely by using the curve B. Thus, if the spring is 14 cms. in length, we use the curve in the following way:—A horizontal line from 14, cuts the curve at a point S; a vertical line from this point strikes the base line at a point T, which indicates 33 grammes. In this way we can convert all our lengths of spring into pressures exerted on the spring by the plant.

The following is a table of actual results:—

Day when Reading was taken.	Time of taking the Reading.	Length of the Spring.	Force exerted by the Plant.
Tuesday	9 a.m.	14·8 cms.	18 gms.
	4 p.m.	14·7 „	20 „
	7 p.m.	14·3 „	28 „
Wednesday	9 a.m.	13·8 „	38 „
	3 p.m.	13·7 „	40 „
Thursday	9 a.m.	13·55 „	42 „
	2 p.m.	13·4 „	44 „
Friday	10 a.m.	12·8 „	55 „
	3 p.m.	12·7 „	56 „
Saturday	9 a.m.	12·4 „	65 „

The plantlet was unable to force the spring to a shorter length than 12·4 cms., it then grew in a strong loop sideways,

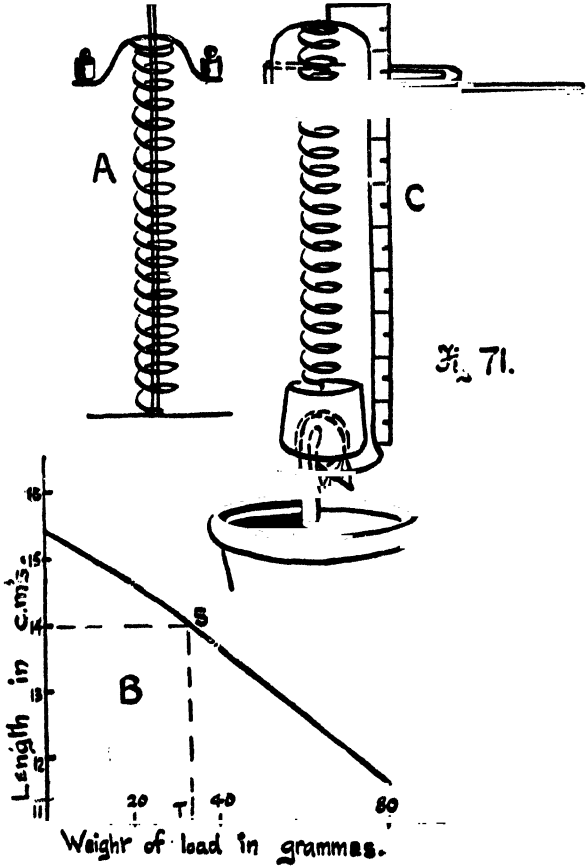


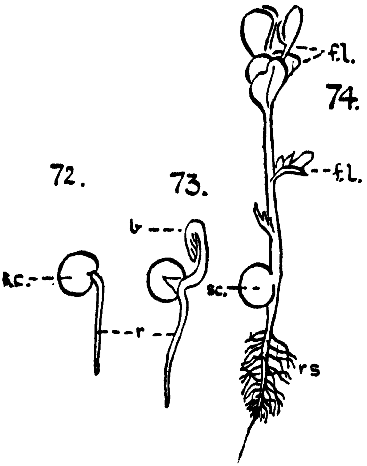
Fig. 71.—Estimation of a Bean's lifting power.—(*A*) Calibration of the duplicate spring; (*B*) The curve obtained from this; (*C*) A growing bean plant compressing a spring.

and pulled its tip out from the tube.

This experiment is a most instructive one, for few students

would suspect that a juicy stem of but half a centimetre diameter possesses a thrusting power of 65 grammes. This experiment throws light on the fact that plants are able to push their stems upwards through the hard soil.

(*C*) **The Pea.—(Figs. 72-74.) Here the root comes out first and grows straight downwards in the soil. (Fig. 72.) It** absorbs water and this is conveyed to the bud between the seed leaves. The bud expands, forces the seed leaves apart slightly, and is dragged out from the seed coat by the elongation and growth of its stem. (Fig. 73.) The "loop" is very pronounced here. By growth in the two arms of the loop, the plantlet obtains a double thrusting power. The top of the loop bears the brunt of the soil pressure and so the delicate bud is protected from injury. Finally the bud is brought well up into the air by the straightening out of the stem. (Fig. 74.)



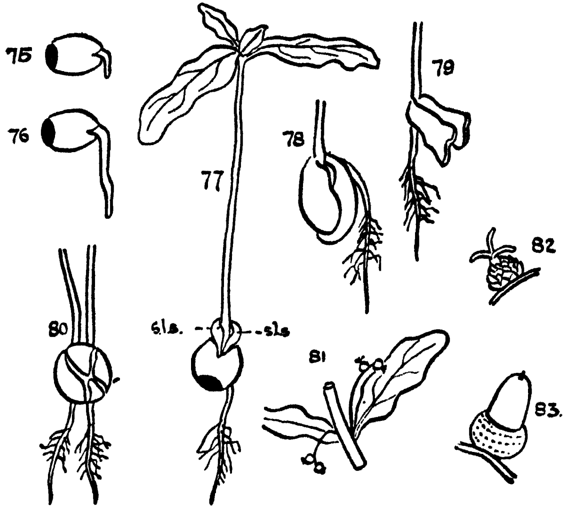
Figs. 72—74.—Germination of the Garden Pea. **—(*b.*) Bud; (*r.*) Root; (*r.s.*) Well-developed Root System; (*s.c.*) Seed Coat; (*f.l.*) Foliage Leaves.**

Where are the seed leaves? They remain inside the seed and gradually shrivel up as their nutriment is withdrawn for the use of the developing plant.

(*D*) The Acorn.—The shrivelling of the seed leaves is seen very well in the acorn (contrast Figs. 78 and 79), where Fig. 79 shows their appearance at a later stage of development than Fig. 78.

The acorn commences germination in the normal way (Figs. 75, 76), the root emerging first. Hundreds of young oaks having developed as far as Fig. 77, can be found growing in an oak wood. In fact we may also find an instructive series of young stages by searching among the dead leaves on the ground on a mild November day.

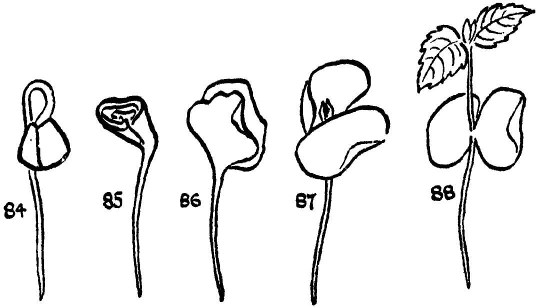
Fig. 80 shows a very abnormal state of things. There are two young oaks, each with perfect stem, root, and pair of seed leaves, growing out from the same acorn. The acorn husk has been removed so that all the four seed leaves may be seen in end view. This is not really remarkable, for a study of the young female flower of oak (Figs. 81 and 82) tells us that there are three stigmas at the tip. We can see the remains of these in Fig. 83. Down in the oak flower there are three oval chambers, each containing one or two ovules. There is then just the remote possibility that six seeds might be produced in the same acorn. Usually one only is developed. It devours all its competitors and monopolises all the nourishment—a proceeding not uncommon in Biology. It is better for the plant to produce one sturdy offspring than six feeble ones.



THE GERMINATION OF AN ACORN (*Figs. 75—83*)
Figs. 75—76.—The Root bursting through the Fruit Wall.
Fig. 77.—Much older stage.—(s.l.s.) Seed Leaf Stalks.
Fig. 78.—Seed Leaves not much shrivelled.
Fig. 79.—Seed Leaves much shrivelled.
Fig. 80.—Two Oaks growing from one Acorn.—(Note the 4 seed leaves.)
Fig. 81.—Young Twig of Oak bearing 4 Female Flowers.
Fig. 82.—A Female Flower magnified.—There are 3 stigmas. Many small leaves invest the flower.
Fig. 83.—Ripe Acorn.—The remains of the stigmas can be seen. The leaves have fused to form the acorn cup.

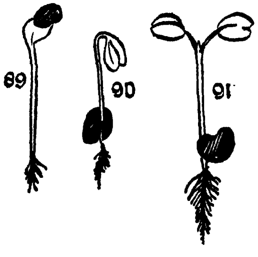
(*E*) THE BEECH.—(Figs. 84-88.) The seed leaves come above ground whilst still enclosed in the nut. (Fig. 84.)

This latter is thrown off by their expansion, and we see how wonderfully they were packed together in the seed. (Fig. 85.) They gradually unfold, lose all traces of their packed crumpled state, and become two large plate-like leaves of green colour and simple shape. (Figs. 86 and 87.) Contrast their simplicity with the true foliage leaves produced after them. (Fig. 88.)



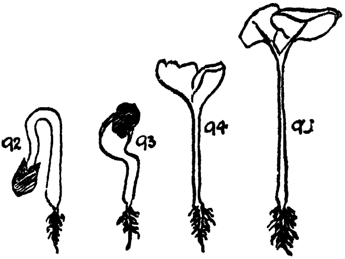
GERMINATION OF BEECH (*Figs.* 84—88).

Fig. 84.—*The Root has emerged from the Nut.*—The nut is held up in the air.
Fig. 85.—*The folded Seed Leaves free from the Nut.*
Fig. 86.—*Seed Leaves expanding.*
Fig. 87.—*Bud shown between the expanded Seed Leaves.*
Fig. 88.—*Two Foliage Leaves expanded from the Bud.*



GERMINATION OF HONESTY (*Figs.* 89—91).

The Seed Coat carried up into the air by the Seed Leaves in Fig. 89.
Seed Leaves making food (*Figs.* 90 *and* 91).



GERMINATION OF BUCKWHEAT (*Figs.* 92—95).

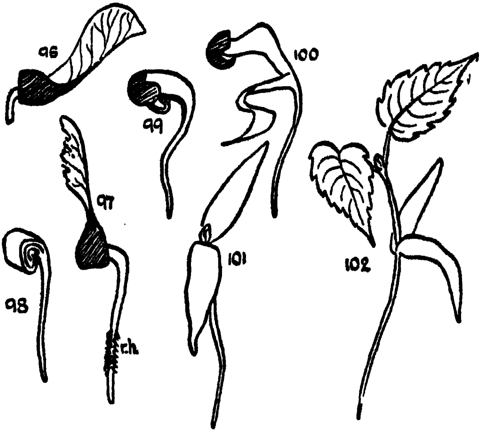
Figs. 92, 93.—*The Seed Leaves carry the Seed Coat into the air.*
Figs 94, 95.—*The Seed Leaves are expanded and are making food.*

(*F*) HONESTY.—(Figs. 89-91.) This is another plant whose seed leaves act as the first leaves above ground. They frequently carry the seed coat up with them (Fig. 89), although they may escape from it quite early and leave it just below the level of the ground. (Figs. 90, 91.)

(*G*) BUCKWHEAT.—(Figs. 92-95.) The looped condition is strongly marked. The seed leaves carry up the hard brown seed coat with them into the air.

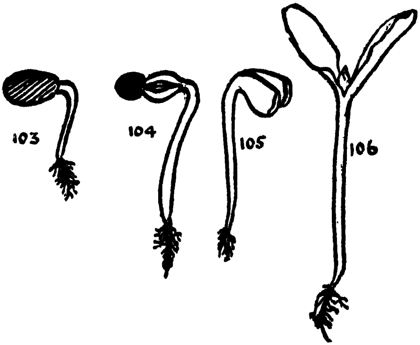
(*H*) SYCAMORE.—All stages here, as in oak, may be picked up beneath the parent tree.

Fig. 98 is the same specimen as Fig. 97, but with its fruit coat and seed coat removed. Figs. 99 and 100 show the plant emerging from the seed coat, the fruit coat having entirely rotted away. The green expanded seed leaves are seen in Fig. 101, whilst their simplicity in Fig. 102 contrasts strongly with the shape and veining of the foliage leaves. The student should contrast these early foliage leaves with the complex leaves produced later and shown in Figs. 534, 535.



Figs. 96—102.—Germination of Sycamore.—For explanation see text. (*r.h.*) Root Hairs.

(*I*) SUNFLOWER.—(Figs. 103-106.) This always germinates easily and is a plant which should be grown by every student. The fruits can be obtained from a corn chandler's at any time of the year. Notice in Fig. 104 how the seed leaves are gradually withdrawing themselves from the fruit coat. The latter is frequently seen attached to one of the seed leaves, nipping it, as it were.



Figs. 103—106.—Germination of Sunflower.—Seed Coat is carried up by the Seed Leaves.

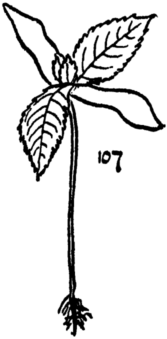
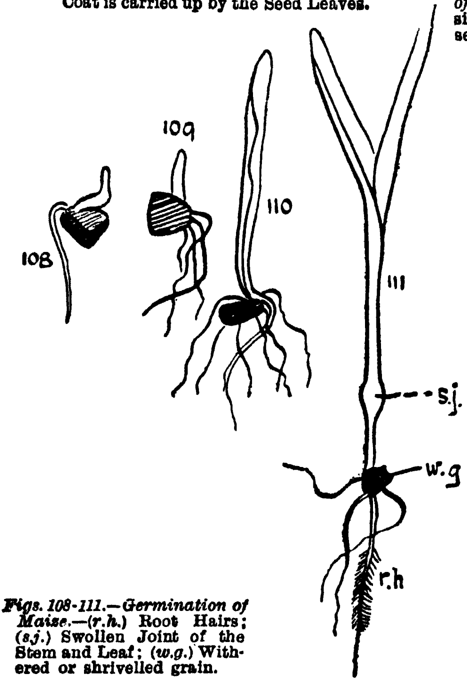


Fig. 107.—Germination of Hemp.—Note the simplicity of the seed leaves.

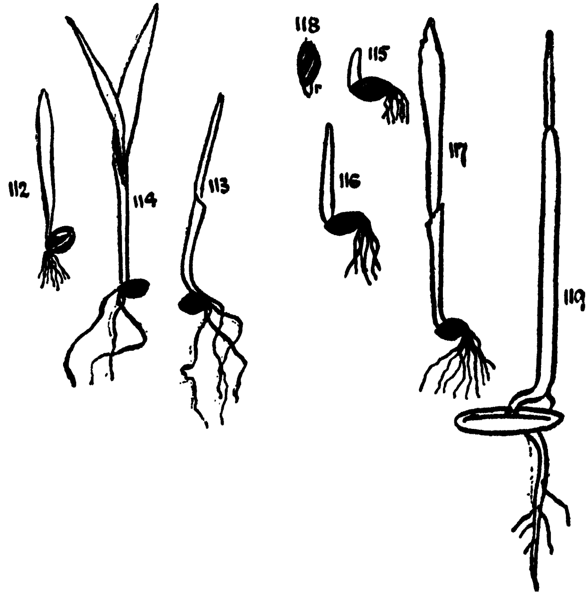


Figs. 108-111.—Germination of Maize.—(*r.h.*) Root Hairs; (*s.j.*) Swollen Joint of the Stem and Leaf; (*w.g.*) Withered or shrivelled grain.

(*J*) HEMP.—(Fig. 107.) This resembles the above in the appearance of its seed leaves above ground, and in their relative simplicity of structure.

3. **Germination of Plants with one Seed Leaf.** (*A*) MAIZE.—(Figs. 108-111.) Both stem and root burst out near each other. We should expect this from our previous study of the structure of the grain. The first root seldom grows any appreciable length. It generally soon divides into a whole group of roots. The one seed leaf always remains inside the grain whilst the foliage leaves which come above ground are closely rolled round each other, forming a spike-like mass which can easily penetrate the soil.

(*B*) WHEAT.—(Figs. 112-114.) Wheat resembles maize in its growth very closely. One may easily verify by its germination the positions of the bud and the root which were almost too small to be seen in the grain.

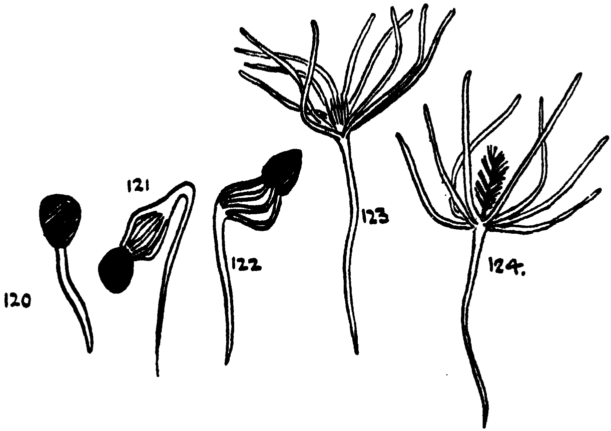


Germination of Wheat (Figs. 112—114); Barley (Figs. 115—118); and Date (Fig. 119).

(*C*) BARLEY.—(Figs. 115 - 118.) Note the immediate formation of a bunch of very many fibrous roots from the first root of the plantlet, which here grows only to a length of a tenth of an inch or so. This formation of a bunch of roots is characteristic of all grass-like plants.

(*D*) DATE.—(Fig. 119.) One would hardly credit that life is contained in the hard stone of the date, yet a specimen, such as Fig. 119, can easily be obtained even in our cold climate.

4. **Germination of a Plant with many Seed Leaves.** PINE.—(Figs. 120-124.) The root emerges first, as usual, then the numerous seed leaves are withdrawn from the seed by the looped growth of the stem. The seed leaves form a ring of narrow green leaves above ground. The first bud lies centrally, and by its elongation all subsequent growth above ground is carried on.



GERMINATION OF PINE (*Figs. 120—124*).

Fig. 120.—Root has emerged from Seed Coat.
Figs. 121, 122.—Seed Leaves pulling themselves out from the Seed Coat.
Fig. 123.—Seed Leaves expanded and functioning as food makers.
Figs. 123, 124.—Development of the Bud in the midst of the Seed Leaves.

SUMMARY.

TYPES OF GERMINATION.

	Examples.
1. Plants with two Seed Leaves.	
(*a*) Seed leaves store up nourishment only, and never emerge from the seed.	Acorn, Pea, Broad Bean.
(*b*) Seed leaves are storehouses at first, but afterwards come out from the seeds, turn green and make food.	Beech, Sycamore, Buckwheat, Honesty Sunflower, Hemp.
2. Plants with one Seed Leaf.	
The seed leaf remains in the seed. Its function is to render the nutriment available for the rest of the growing plant.	Maize, Wheat, Barley, Date.
3. Plant with many Seed Leaves.	
Seed leaves (about 12) come above ground, are green, and make food.	Pine.

Plants with two seed leaves (Cotyledons) are termed Dicotyledons ; those with one seed leaf Monocotyledons.

PRACTICAL.

1. Germinate the above-mentioned plants in chimney glasses and in boxes. Draw successive stages in the growth of each.
2. **Measure the lifting power of a broad bean seedling.**

CHAPTER VI.

Food.

1. The Nature of Protoplasm.—The simplest creatures, whether animals or plants, consist merely of a single speck of protoplasm or living substance, and the word "cell" is usually applied to such a tiny aggregation of vital material.

As we proceed higher in the scale of life we find organisms composed of many coherent cells; and in every large animal or plant there are millions of these cells, each forming an integral part of its structure.

Scientists as yet are much in the dark as to the actual composition of protoplasm. It is *living* material, and since on chemical examination it immediately breaks down into a large number of derivative bodies (proteids, fats, sugars, etc.), we cannot say *how* these were combined together, or whether indeed they were actually present as such, in the living state.

Protoplasm baffles enquiry as to its structure, but we are well acquainted with its manifestations of vitality. It will be well to formulate these here, for by their means we are enabled to distinguish living from dead substance.

(1) Protoplasm possesses the power of movement.

(2) It can ingest (or take in) its food from without.

(3) It has the power of producing or secreting ferments by the action of which upon the food the latter is rendered soluble or digested.

(4) It can absorb this food into its own nutriment-carrying fluids.

(5) It can incorporate, synthesise or assimilate such nutriment into itself, *i.e.* it can repair or renew its *living* self by utilising *dead* constituents.

(6) It is continually respiring or being broken down into simple substances; the final products of the whole chain of destructive process being carbonic acid gas, water and nitrogenous waste bodies. Since the above decom-

positions are really a series of oxidations, an intake of oxygen gas is vitally necessary.

(7) It has the power of excreting or expelling from itself the above waste matters and also a great variety of other materials which it has produced or secreted.

(8) In addition to repairing itself it can *grow* or build up *additional* protoplasm. This growth bears not the slightest analogy to the cumulative growth in size and thickness of dead matter, *e.g.* the size of mineral crystals when deposited from a super-saturated liquid, or the thickness attained by a snail shell or a pearl. In these latter cases we merely have the deposition of successive external layers of dead matter, whereas in the growth of protoplasm each living particle is exercising (*a*) a selective, (*b*) a synthetic action. In other words dead substances increase by passive accretion from without; living substances by an active incorporation in, and by means of, every intimate living particle.

(9) It has the power of reproduction. This is not merely the physical separation of a portion of the protoplasm when it has attained an increased bulk. It is a vital process which is always preceded by a very exact division of the nucleus—the most essential part of the cell.

(10) It is extremely irritable or responsive to stimulation. The chief stimuli affecting animal protoplasm are mechanical, chemical, electrical and nervous. On the plant side we shall deal mainly with the responses evoked by contact, light, moisture, temperature and gravity. The mere enumeration of the above stimuli shows us how very sensitive protoplasm is to changes in its environment, and how consequently it is able to adapt itself to varying conditions of life.

2. **Requirements of Protoplasm.**—In our previous work we have regarded protoplasm from the *vital* point of view, and the main conception that the student should grasp is that protoplasm is an infinitely complex and unstable body whose *living* character is the direct result of continuous ill-defined chemical changes.

There are two series of these changes:—

(1) Anabolic or Constructive: commencing with food (proteid, fat, carbohydrate) and concluding with the incorporation of this into actual living material.

(2) Katabolic or Destructive: commencing with protoplasm and giving water, carbonic acid gas, etc., as final products.

It is imperative here to note that (i.) each of the above is a *series* of chemical interactions; (ii.) most probably some substances produced during Katabolism are again used in the Anabolic process. As a matter of fact we merely know the *ends* of the processes: that food stuffs (proteids, fats, sugars, etc.) and oxygen are utilised; and that the carbonic acid gas, water and nitrogenous waste substances (asparagin, leucin, tyrosin or urea) are produced; but we know little or nothing of the exceedingly complex series of actions and interactions which necessarily are involved in the assimilation of the food-stuffs and the production of the waste substances.

There must exist a close connection between the absorption of oxygen and the production of heat and energy. For many years it was thought that highly combustible non-nitrogenous food stuffs such as fats and sugars were taken into the body for combustion *by* the protoplasm, but it is better to regard them as becoming *actually incorporated* into the living material prior to any such "combustion." The general result of modern research is to throw doubt upon the theory which regards a creature as a kind of engine consuming fuel and expressing this consumption in an equivalent amount of energy. The better conception is that both nitrogenous (proteids) and non-nitrogenous (fat, sugar, starch) foods are necessary for the synthesis of living material.

Nevertheless, it is perfectly true that the highly combustible fats and sugars impart much potential energy to the protoplasm on their assimilation, and may be regarded as heat or energy producers from this point of view.

In older text books proteids will be found treated as the sole tissue-forming food stuffs. They *are* tissue-forming it is true, and this is their main function, for all protoplasm contains proteid constituents, but this work of tissue-formation is shared also by the fats and sugars, even though the synthesis of the latter may be, and probably is, only temporary.

3. **Ideal Foods.**—If we were to seek for the most ideal foods on the animal side we should most likely choose milk and eggs; the former because young mammals use it solely for their development for a considerable period, the latter because the chick develops from the mere speck to the fully-fledged bird by means of the nutrition contained in the egg.

MILK.—De Chaumont gives the percentage composition of cow's milk as follows :—

Water	86.8
Proteids	4.0
Fat	3.7
Sugars	4.8
Mineral Salts	0.7

The proteid matter is casein, whilst the non-nitrogenous food is present in dual form: (*a*) Fat (*i.e.* the cream); (*b*) Sugar (lactose or milk sugar).

The student may feel surprised that these constituents are present in such small amounts, but it should be borne in mind that this natural liquid is to be presented to the weak immature digestive system of a young creature. It is important to note that in milk we have both nitrogenous and non-nitrogenous foods.

EGGS.—Quoting again from the above authority, the composition of an egg (omitting the shell) is as follows:—

Water	73.5
Proteids	13.6
Fat	11.6
Sugars	*none*
Mineral Salts	1.3

What is specially evident from the above figures is the greater concentration of the nourishment in an egg than in milk. The reason is not far to seek; the store contained in the egg is the only food available for the chick during the whole of its incubation period. Note also the non-nitrogenous food is entirely in the form of the highly combustible fat, thus affording an economy in space.

The proteid matter is mostly in the form of albumen, both in the white and yolk of the egg, whilst the fat is mainly stored in the yolk. The storage of both nitrogenous (albuminous) and non-nitrogenous (fatty) food again emphasises the necessity of each (Fig. 125).

125

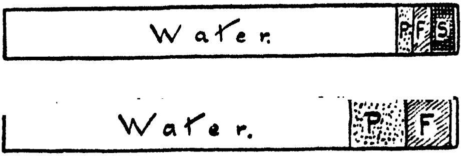


Fig. 125.—Comparison of the composition of Milk (upper) and Egg (lower) (*p.*) Proteid; (*f.*) Fat; (*s.*) Sugar.

4. **The Complexity of Food Materials.**—Proteids contain carbon, hydrogen, oxygen, nitrogen and sulphur, but this by no means gives us any idea of their complexity. Each smallest molecule of proteid consists of many atoms of these elements. Similarly with the non-nitrogenous foods:

fats, sugars and starches. These consist, it is true, of the elements carbon, hydrogen and oxygen, but there are many atoms combined here also. A moment's reflection will show that it is necessary for both nitrogenous and non-nitrogenous foods to be complex, because they are to be immediately transformed into the infinitely complex protoplasmic substance.

5. Characteristic Tests for Foods.

FOODS.	EXAMPLE TAKEN.	EXPERIMENT.	RESULT.	INFERENCE.
Proteid.	Raw white of egg.	1. Boil with Millon's Reagent.	Precipitate pink on boiling.	Presence of proteid.
		2. (*a*) To NaOH solution add $CuSO_4$ solution, drop by drop.	(*a*) Blue coloration is obtained.	
		(*b*) Add white of egg.	(*b*) Blue turns violet.	Presence of proteid.
		(*c*) Boil.	(*c*) Deep violet colour.	
	Peptone solution.	3. Boil with Millon's Reagent.	Precipitate pink on boiling.	Peptone is a proteid.
		4. (*a*) To peptone solution add NaOH in excess, then weak $CuSO_4$, drop by drop.	(*a*) Pink colour produced.	Presence of peptone.
		(*b*) Add more $CuSO_4$.	(*b*) violet colour.	
Fat.	Any common fat.	5. Greases paper.		
		6. Stain with Osmic acid.	Slowly darkens to a black colour.	Presence of fat.
		7. Stain with Alkanet tincture.	Stains a pink colour.	Presence of fat.
Starch.	A paste made by boiling potato (or other) starch.	8. Iodine solution added.	Blue colour.	Presence of starch.
Sugar.	Grape Sugar.	9. Boil with KOH and $CuSO_4$.	Red precipitate.	Presence of grape sugar.
	Cane Sugar.	10. Boil with KOH and $CuSO_4$.	Red precipitate absent.	Absence of grape sugar.
	Cane Sugar.	11. Boil with H_2SO_4 then test as 10.	Red precipitate.	Converted into grape sugar.

The KOH should be strong, the $CuSO_4$ should be weak, solutions.

6. **The Meaning of Digestion.**—In order for any animal or plant to utilise its food, the latter must be made soluble. True digestion consists solely of this process. The protoplasm of living creatures produces certain substances called ferments, which have the power of causing the chemical changes necessary to convert an insoluble food into a soluble one.

Examples of digestive ferments are well seen in the animal body.

(*a*) Insoluble starch is converted into soluble sugar by the ferments ptyalin and amylopsin contained in the saliva and pancreatic juice respectively.

(*b*) Insoluble fat is turned into soluble soap by the ferment (steapsin) of the pancreatic juice.

An important point to be noticed is that not only must the food be turned into a soluble form, but also such soluble substance must be diffusible, *i.e.* capable of passing through cell walls and living membranes.

7. **Examples of Digestion.**

(i.) DIGESTION IN ANIMALS.

(*a*) If a little starch be placed in a test tube with saliva, and the test tube kept for a while at the body temperature in a water oven, the starch will be found to gradually disappear, and by testing chemically sugar is shown to be present.

(*b*) If shreds of white of egg be similarly treated with an artificial gastric juice (liq. pept. Benger), they will disappear. On applying food tests (3 and 4) peptone is found to be present.

(ii.) DIGESTION IN PLANTS.

(*a*) If barley grains be crushed and the powder boiled, iodine (Test 8) shows starch to be present.

(*b*) The sprouts broken off from germinating barley grains will give a sugar reaction. (Test 9.)

This conversion of starch to sugar in the germinating stage is brought about by the ferment *diastase* produced by the seed leaf. (Fig. 33.)

N.B.—The ptyalin of the saliva of animals is often called *animal diastase.*

8. **Foods stored up in Seeds.**

(*a*) STARCH.—A white powder settles at the bottom of the vessel when wheat flour is kneaded in a muslin bag under water. Tested with iodine this powder is found to be starch. Note the large starch grains contained in the cells of the bean seed. (Fig 43.)

(*b*) PROTEID.—The same figure shows smaller grains in the cells. These are of proteid composition. The extent of proteids in this seed is well seen by boiling up a few thin slices of a soaked runner bean with Millon's reagent (Test 1). Both surfaces of the slices are deeply stained pink. Test 2 gives a good result if soaked bean scrapings be used. A pronounced violet shade is obtained. The sticky mass of glutin left behind in the muslin bag in the starch experiment above is also proteid. Boiled up with Millon's reagent the whole mass is coloured pink. We have been dealing so far with very minute proteid grains stored up in seeds. The castor oil seed has very pronounced proteid grains in its cells. (Fig. 126.)

(*c*) FAT.—Castor oil seeds also contain much fat. This is easily seen by crushing the seeds upon a piece of white paper, and noting the grease spot produced. The fatty nature is very evident on chewing a small part of the seed. In this seed the plantlet is embedded in a tissue rich in both fat and proteid. If a microscope be available, tests 6 and 7 afford the means for recognizing the globules of fat whilst contained in the cells that produced them.

126

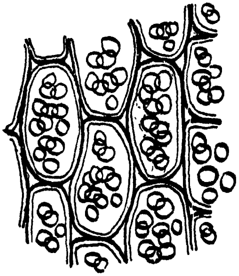


Fig. 126.—A few Cells or Chambers in the Castor Oil Seed, showing the proteid grains stored up for the use of the young plant (highly magnified).

127

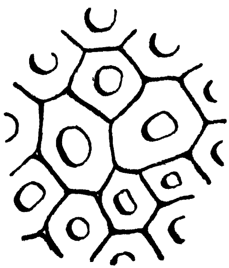


Fig. 127.—A few Cells from a Date Stone, showing the greatly thickened cellulose walls. The circles are the cavities of the cells.

(*d*) CELLULOSE.—This is the material of which the delicate cell walls of plants are made. It is a carbohydrate, closely allied to starch in composition, and so has a definite food value, but animals usually find cellulose extremely indigestible. There is one plant—the Date—however, which stores up the bulk of its reserve food in this form. The hard "stone" of the date, shown germinating in Fig. 119, consists almost entirely of cellulose. A microscopic view of a few cells from a date stone is given in Fig. 127 to show how the cellulose walls are greatly thickened.

9. **Amount of Food stored up in Seeds.**—When we think how seeds germinate in complete darkness underground, and so are unable to make any sugary food for themselves, we can quite understand how it is that they are always so closely packed with food. We can gain a good idea of the amount of food stored up in seeds by first germinating them, and then allowing them to grow in the dark in damp sand or with their roots dipping into water, (Fig. 128.) A bent piece of wire is used to support the seed so that only its roots are in the liquid. Since we are growing the plants in a dark box or cupboard they cannot turn green and make food for themselves, nor does water or damp sand afford them any food. They are thus entirely dependent on the food which was stored up by the parent plant in the seed.

128

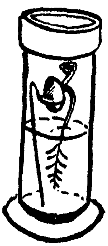


Fig. 128.—Experiment to find how much food was stored in the Seed.

SUMMARY.

FOOD.

Its Necessity: 1. To build up the tissues.
2. To maintain the vital activities and to preserve a temperature at which these are possible.

Protoplasm or Living Substance is capable of—

1. Movement.
2. Ingestion.
3. Secretion.
4. Absorption.
5. Assimilation.
6. Respiration.
7. Excretion.
8. Growth.
9. Reproduction.
10. Irritability.

Chemical Changes in Protoplasm:—

Metabolism.
- Anabolism—The construction of protoplasm from proteids, fats, sugars, etc.
- Katabolism—The respiratory process. A destructive change: protoplasm gradually becoming broken down into H_2O, CO_2, and nitrogenous waste substances.

Requirements of Protoplasm:—

1. Both nitrogenous and non-nitrogenous foods (for anabolism).
2. Oxygen (for katabolism).

Food.—Food stuffs must be complex in order to be synthesised almost immediately into the living material.

Milk and eggs are "perfect" foods, since they contain all the food stuffs necessary for protoplasmic synthesis.

Digestion.—All food has to be digested or rendered soluble before an organism can make use of it. The digestive process is carried on in both plants and animals by means of ferments. A ferment only acts on one particular kind of food.

Storage in Plants.—Plants store up both nitrogenous and non-nitrogenous food stuffs in their seeds—the former generally in the form of proteid grains, the latter as starch grains.

In the date "stone" cellulose is the reserve material.

In castor oil seeds a large amount of fat is stored up instead of starchy material.

Plants store food up in their seeds so that the young plants may utilise this:

(*a*) For the production of root system.
(*b*) For growth of stems upwards through the soil.

Until a plant's leaves are exposed to the light it can make no food whatever for itself.

PRACTICAL.

Perform all the experiments described in this chapter.

CHAPTER VII.

The Varieties, Functions and Behaviour of Roots.

1. **The Work done by Roots.**—In order to understand the appearance, internal structure, and behaviour of roots, we must constantly keep before our minds the two main functions. These are :—

(*a*) To anchor the plant in the soil.

(*b*) To absorb water and mineral salts from the soil.

2. **The Two Chief Varieties of Root Systems.**—When a plant is pulled up from the ground its roots generally present a confused interwoven or tangled appearance. Comparison of the root systems of a number of common plants shows us that they naturally fall into two varieties—

(i.) Taproot system. (ii.) Fibrous root system.

The taproot system is always characterised by the presence of a main root which grows straight downwards in the soil, and from which lateral roots are developed in a varying number of vertical rows. (Fig. 3B.) The swollen root of beet shows two such rows very clearly indeed. (Fig. 129.) Frequently in other plants there are five such rows of rootlets. These rootlets grow out in five definite, more or less horizontal directions and thus penetrate the ground on every side. Smaller roots spring from these rootlets. These grow in every direction from their parent roots—up, down, and sideways, so that the ground is most thoroughly penetrated by the root mass.

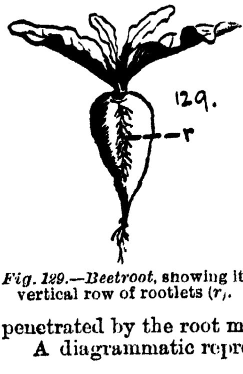
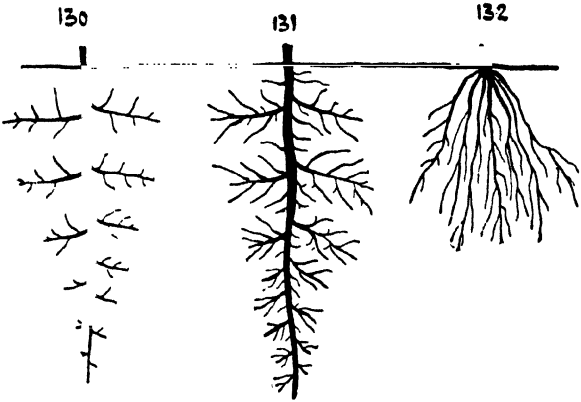


Fig. 129.—Beetroot, showing its vertical row of rootlets (*r*).

A diagrammatic representation of such a branched system is shown in Fig. 130. The student should not, however, expect a living specimen to present the perfect regularity of Fig. 130. There is a potent reason for much variation from this regular arrangement of roots in the latter part of the plant's life. We shall see further on in the chapter that water and mineral salts are only absorbed by the tip regions of roots. Thus, the ground lying nearest the taproot in Fig. 130 would soon become untapped of its materials, and so we find that new young roots are produced from older parts wherever the ground is not being utilised by the absorptive regions of other roots. Contrast Fig. 131 with 130.



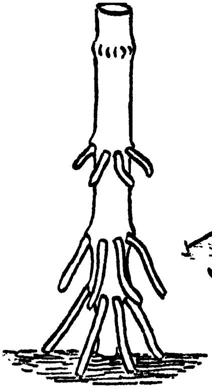
Diagrammatic Views of Root Systems (*Figs. 130—132*).

Fig. 130.—Young Tap Root System.
Fig. 131.—Older stage of Tap Root System.
Fig. 132.—Fibrous Root System.

The second variety of root arrangement is the fibrous system. Here no main root can be seen. (Fig. 132.) There are many roots of approximately equal length, and smaller roots spring off from all of these. Grasses and their allies all have root systems of this type, whereas the taproot system is found in large plants. If a grass be an exceptionally tall plant, this fibrous type of root system is not strong enough to prevent upheaval of the plant by the wind. Special provision is made by the maize plant (which frequently grows over ten feet high even in our own country) to strengthen its root system. (Fig. 133.)

Rings of roots arise from the stem above ground. These grow obliquely downwards, reach the soil, and thus give a support to the tall maize stem in precisely the same fashion as an army bell-tent is kept firm by its tent ropes. (Fig. 134.)

133



134

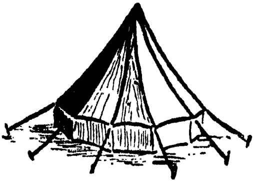


Fig. 133.—Buttress Roots springing out at various levels from a Maize Stem.

The above two systems of root branching should be carefully examined from the two following points of view:—

(i.) Does the method of branching further the root's work of anchorage?

(ii.) Does it further absorption by enabling the plant to avail itself of all the water, etc., within its reach?

The answers to these questions are evident.

3. **Other Functions of Roots.**—The swollen roots of turnip, carrot and beet are clearly performing another function. If slices of these are boiled and the liquids treated by food test 9, we find a red precipitate is produced in the case of turnip and carrot, but not with beet juice. Turnip and carrot therefore contain grape sugar, beet does not do so.

A little beet juice, however, gives the grape sugar reaction after it has been boiled with sulphuric acid, owing to what is called inversion. The cane sugar, which the beet contains, is converted into grape sugar by the sulphuric acid. These swollen roots subserve a storage function. During the first year of their growth the above plants store up foods in their roots, and the next year this is utilised for the formation of a long stem, flowers, fruits and seeds—such plants being termed biennials.

A totally different work is performed by the small roots which grow out from an ivy stem as it is growing up a wall or a tree trunk. These are produced on the side of the stem nearest the support, and by growing into the crannies of the latter the ivy plant is able to hold its leaves well out to the light. (Fig. 135.)

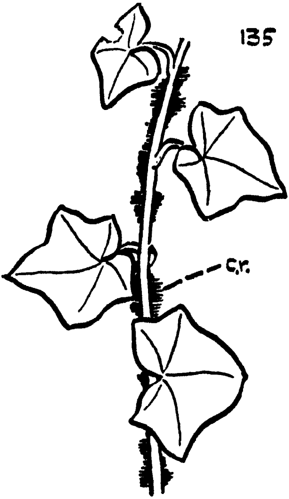


Fig. 135.—Ivy—climbing twig. (*c.r.*) Clasping roots.

Were we to go further afield to examine roots found in tropical regions, we should find them performing most diverse and unexpected kinds of work. Space precludes us from dealing with these in any detail, but the main types may be briefly mentioned here.

(*a*) Many plants (particularly orchids) grow perched on the branches of trees. Their roots hang down into the air, and being spongy outside absorb moisture from the air. Inside they are green, and so can make food like leaves. (Fig. 570.)

(*b*) Some plants have roots similar in type to the buttress roots of maize. (Fig. 133.) These frequently grow into 'planks,' buttressing the stem on every side.

(*c*) In other plants these roots become a dense thorny mass, and so afford protection against animal attacks.

(*d*) In the Banyan tree there is a trunk with branches above ground in the usual way of trees, but roots arise from these branches and grow downwards in the air until they reach the ground. They then branch in the soil as ordinary roots do. The strange thing is that the above-ground portions of the roots grow thicker and thicker year by year, and in time look like massive stems or trunks. They thus serve as pillars, supporting the spreading branches of the tree, which now to all appearance is a grove of trees.

4. **Meanings of the words Irritability and Stimulus.**—In its popular sense we use the word 'irritable' to describe a person who is very easily put out of temper by trifling occurrences. His temperament is such that he immediately responds to slight alterations in his environment. In physiology, the word 'irritable' has a more definite meaning.

We have already noted the powers possessed by protoplasm in a previous chapter. Any condition, whether external or internal, which will cause the living material to exhibit these powers in a greater or less degree is termed a stimulus, and protoplasm is said to be *irritable* because it responds to these stimuli. Irritability is the power of responding to stimuli.

5. **The Root Considered as an Irritable Organ.**—We will now regard the root from this point of view, first examining its behaviour, and then seeking for the stimulus which has caused it to act in this particular way.

(1) INFLUENCE OF GRAVITY.—If a bean seed be germinated in the three positions given in Fig. 136, it is found that the first root always turns downwards. That there is a downward force attracting the root can be seen from another experiment (Figs. 137-140): Beans whose first roots are just protruding are pinned on a vertical disc of cork with all roots pointing towards the centre. (Fig. 137.) After some days they present an appearance as in Fig. 138. Obviously something has caused a downward growth in these first roots.

136

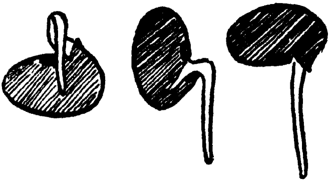
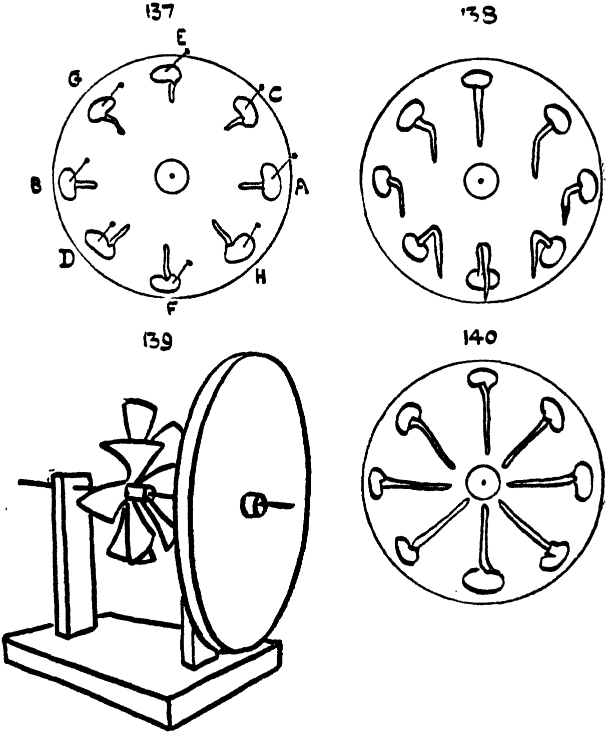


Fig. 136.—The first Root of the Bean always turns downwards. (The seeds are shown in the same positions as sown.)

If another set of beans be pinned on the disc and it be rotated vertically at a slow uniform rate by clockwork, or by water power, as in Fig. 139, we find that the roots grow directly inwards towards the centre. Let us assume that it is the force of gravity causing the downward growth. If we do so, we can explain why the roots grow straight inwards towards the centre, because if the rotation is uniform the bean will be just as long in the position *B* (Fig. 137) as it is in position *A*.

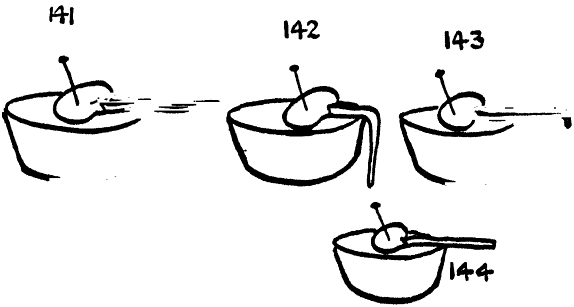


THE ACTION OF GRAVITY ON ROOTS (*Figs. 137–140*).

Fig.* 137.—*Beans pinned in position on a cork disc.
Fig.* 138.—*Result of growth during 1 week (still).
Fig.* 140.—*Result of growth during 1 week (rotated vertically).
Fig.* 139.—*View of simple rotating instrument. Water from a tap falls on the vanes and causes a constant rotation.

When in the *A* position gravity will tend to curve the root in the downward direction as shown, but when the *B* position is reached this downward direction will be an upward one, and consequently gravity will pull the root straight again. Similar considerations hold for all other pairs of positions, as *CD*, *EF*, *GH*. Thus the rotation of the disc would neutralise gravity's attractive force.

Again, suppose we pin a bean so that its root freely projects in the horizontal direction. (Fig. 141.) We should expect it to bend as in Fig. 142. It does not do so; it bends quite near its tip. (Fig. 143.) This would point to the fact that all parts of the root are not equally irritable to the stimulus of gravity. We can clinch this matter by cutting off the tip of a bean root and then pinning up as before. (Fig 144.) It does not bend downwards, since we have removed the sensitive or irritable portion.



EFFECT OF GRAVITY ON ROOTS (*Figs. 141—144*).

Fig. 141.—The Root pinned in position on a cork.
Fig. 142.—How we should expect it to behave.
Fig. 143.—How it actually behaves.
Fig. 144.—It does not bend downwards when the tip is cut off.

Fig. 130 also shows us another valuable point. In the tap root system the roots do not all grow down; some grow upwards, quite in defiance of gravity. From these considerations it is clear that only the tip of the *main* root is irritable to the gravity stimulus.

(2) THE INFLUENCE OF THE POSITION OF THE PARENT BODY. Whenever a rootlet grows from its parent, it continues outwards in a definite direction. In somewhat unscientific language, we can describe it as behaving just as though it were *trying* to get as far as possible from the root or stem from which it has sprung. Supposing the rootlet meets some obstacle such as a stone or some

other hard substance, through which it is unable to penetrate, it grows round this and then continues its outward journey at the first available opportunity. We do not know the mechanism by which this is brought about. We might conceal our ignorance by talking glibly about "exotropic behaviour," etc., but all we actually know is that the rootlet behaves as if it *were* repelled by the parent.

(3) THE INFLUENCE OF MOISTURE IN THE SOIL.—Moisture in the soil exercises a very definite stimulating influence on the growth of roots. The latter always grow in the direction of the moister soil regions. Here, again, we cannot say how this is brought about, we only know that it is so.

(4) THE INFLUENCE OF LIGHT.—Have you noticed how very seldom indeed we see the roots of plants growing above the soil? The thick woody roots of trees are not referred to here; they have been gradually laid bare by the wearing away of the soil from above. Why should not the young delicate, and therefore sensitive, rootlets, which we see growing upwards in the soil in Fig. 130, come up above ground?

Many biologists explain this by saying that the rootlets would appear above ground were it not that the light drives them back. Most probably this action of light is exaggerated, for a very plausible explanation of this behaviour of rootlets in not appearing above ground is that they are attracted by the moisture in the soil, which is greater in amount than that contained in the air above. Support is given to this opinion in that plants, such as mangroves, inhabiting tropical swamps where the air above is saturated with moisture, frequently send up roots above ground.

It is interesting to note, however, that the climbing roots of ivy (Fig. 135) are undoubtedly repelled by light. They are especially sensitive to this repellent stimulus, and so grow deeply into the chinks and crannies of the supporting structure.

6. **How Irritability Aids Root Functions.** It is left, as an instructive exercise, for the reader to consider each of the above four stimuli in the light of their rendering the root an efficient organ of

(i.) Anchorage,
(ii.) Absorption.

SUMMARY.

Work done by Roots:—(*a*) anchorage; (*b*) absorption; also occasionally:—(*c*) storage; (*d*) climbing.

Main kinds of Root Systems:—

(*a*) Tap: One main root, many lateral ones.

(*b*) Fibrous: No main root, many of approximately equal length.

Stimulus.—Any change of condition which invokes a response from a living organism.

Irritability.—Is the capability of responding to a stimulus. It is a fundamental property of living matter.

The Root is an Irritable or Sensitive Organ.

(*a*) The tip of the main root is attracted by the force of gravity.

(*b*) Roots always grow as far as possible away from the parent which has produced them.

(*c*) All roots are attracted by moisture.

(*d*) Climbing roots in ivy are repelled by light.

All the above aid the root in one or both of its main functions of anchorage and absorption.

PRACTICAL.

1. Pull up weeds and sketch their root systems.
2. Sow soaked seeds in sawdust and examine the root systems at various stages.
3. Prove that a carrot and a beetroot contain grape and cane sugar respectively.
4. Perform an experiment to show that the main-root tip alone is sensitive to gravity.
5. Account for the irregularity, so often found, in the direction of the growth in main roots of common weeds.
6. Find out what decides whether a carrot shall be of a good or a bad shape.
7. Germinate barley grains, and note the time which elapses before fibrous roots are produced.
8. Grow cress seedlings in a shallow box having a bottom made of fine wire gauze. Hang up the box near the window. Observe and explain the behaviour of the roots after they have grown through the gauze.
9. Arrange germinating sunflower fruits as in Fig. 163. Cover the test tube with black paper except a long narrow chink. Does the root grow away from the light?

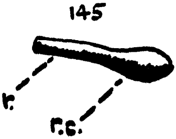
CHAPTER VIII.

The Structure and Work of Roots.

A. HOW THE STRUCTURE OF A ROOT FITS IT FOR ITS LIFE AND WORK IN THE SOIL.

1. **The Root-Cap.**—We should naturally expect roots to be fitted for their mode of life and the work they have to perform. First of all we notice that the root lives in a far different environment from that which envelops stem and leaves. It has to grow and force its way through hard resistant soil; and from the soil it has to abstract water and mineral salts.

The root tip bears a special protective envelope—the root-cap—to prevent the delicate growing region being bruised and injured by rubbing against the hard soil particles. (Fig. 145.) It will be noticed that the end of every root is slightly swollen: this swelling is the root-cap above mentioned. It naturally



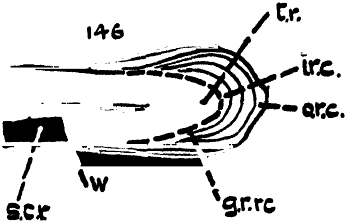


Fig. 145.—Tip of a Root (r.) *magnified to show its Root Cap* (r.c.).
Fig. 146.—Diagrammatic view of same, cut lengthways. (*g.r.r.c.*) Growing region of root cap; (*i.r.c.*) Innermost region of root cap; (*o.r.c.*) Outermost region; (*t.r.*) Tip of the root proper; (*s.c.r.*) Soft-celled tissue of the root; (*w.*) Woody water-conducting part of the root.

follows that this protective sheath or guard will itself be gradually worn away by friction. Yet it remains of uniform thickness, because it is at the same rate renewed from within. (Fig. 146.) We get a good idea of the growth of the root-cap by comparing it closely with the constant wearing away and renewal of the skin of the human body.

2. The Root Hairs.—Just behind the root-cap there is about an inch or so of root clothed with a fleecy mass of root hairs. (Fig. 147.) These should be carefully distinguished from rootlets. You will see these splendidly if you germinate some cress seeds on a piece of flannel placed in a saucer of water. These root hairs have extremely thin walls, and they are the only parts of the root which absorb water and mineral substances.

147

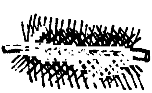


Fig. 147.—Small part of a Root (near its tip), magnified to show its root hairs.

The way in which they work is detailed below. They have an exceedingly short life, dying away behind as fast as new ones are produced in front, and so always clothing the region just behind the root tip. An enlarged view of a few root hairs

148

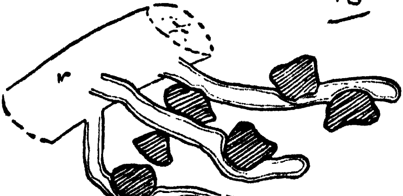
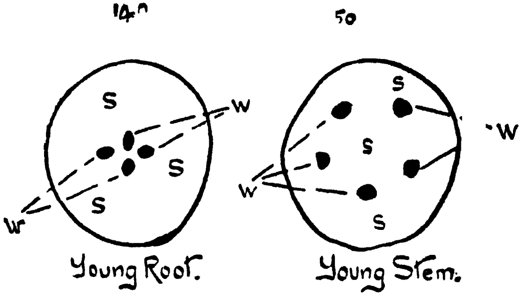


Fig. 148.—Small part of a Root with 3 root hairs shown. (Note how closely the root hairs invest the soil particles).

is given in Fig. 148. Notice how close they are to the soil particles; some of the latter seem almost to be embedded in the walls of the root hairs.

3. The Position of the Strong Tissues in a Young Root.—The strongest material seen in a young root when cut across (Fig. 149) consists of the wood, whose large water conducting tubes or vessels lie right in the centre of the view. If we contrast this with a young stem cut across we find that the woody parts are in a ring some distance from the centre. (*Fig. 150.*) There must be some reason for this central arrangement of the wood. Let us examine what kind of force the young roots will have to withstand. When the wind blows against the plant above ground, or when a person tries to pull a plant from the soil, the effect on the roots will be a pull lengthways. (Fig. 151.) The best way to resist such a pull is to aggregate the strong woody parts into a central rope-like mass, and this almost invariably occurs in young roots.



Figs. 149, 150.—Young Root and Stem cut across to show the disposition of the strong woody parts (w.) *and the softer parts* (s.).

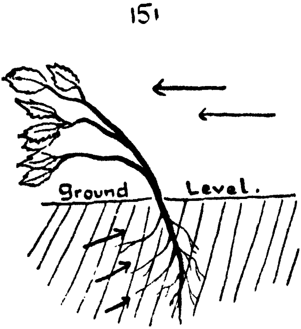


Fig. 151.—Effect of side wind on the roots of plants.

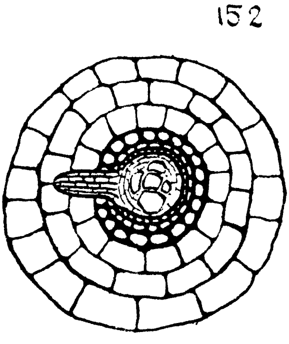


Fig. 152.—A Fern Root cut across, showing a young root growing out from a deep-seated region.

4. The Protection of the Young Root in its Earliest Stages of Growth.—When we cut cross sections (slices) of roots, we frequently find young roots embedded in them, yet from an external examination we should not have suspected their presence. Fig. 152 shows a young root embedded in an older one. As a matter of fact the young root starts to grow deep down in the parent. It gradually bores its way out, so that often we can tell where a young root is about to emerge, because it causes a slight bulge on the surface of the parent. What is the significance of this deep-seated origin? When we consider the delicate nature of the baby rootlet, together with the hard character of the soil through which it is soon to grow, we can appreciate the efficiency of the protection afforded it by the older root during the earliest stages of its life.

B. HOW ROOTS ABSORB WATER AND MINERAL SUBSTANCES.

5. **Osmosis.**—By osmosis we mean the passage of water and dissolved substances through a membrane. An experiment will make this definition clearer. If a thistle funnel has its end covered with a piece of bladder and partly filled with sugar solution, as shown in the diagram, we find that on immersion in a vessel of ordinary water the level of the liquid in the funnel tube gradually rises. (Fig. 153.) It is as though the sugar contained in the funnel attracts more water through the bladder. At the end of a few days the water in the outer vessel will have acquired a distinctly sweet taste; evidently some of the sugar has passed outwards through the bladder. This passage of water one way and sugar the other will go on until there is an equal strength of sugar solution on both sides of the membrane.

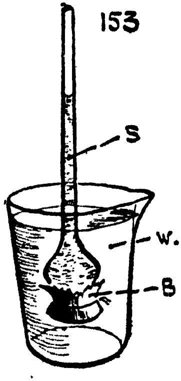


Fig. 153.—Experiment illustrating Osmosis.
(s.) Sugar solution.
(w) Water.
(b.) Bladder tied over the mouth of the thistle funnel.

6. **The Root Hairs Absorb Raw Food Materials by Osmosis.**—Let us apply this principle to the action of the root hairs. Structurally, a root hair is the outgrowth of an outermost cell of the root. (Fig. 154.) It is bounded by a delicate cell wall made of cellulose, and within this there is a thin film of protoplasm or living material. The whole of the

interior of the root hair is a relatively large cavity filled with sap. This sap is very important in the work of the root hair, for it contains substances of an acid nature which have a great attraction for water.

These attractive substances have been made by the protoplasm of the root hair, and it is due to their attraction of water that there is any sap in the hair at all. They act in just the same way as the sugar in the funnel (Fig. 153), causing more and more water to enter into the root hair until the latter is turgid or distended with sap. The only soil water that the root hairs utilise is the thin films of water closely surrounding the soil particles.

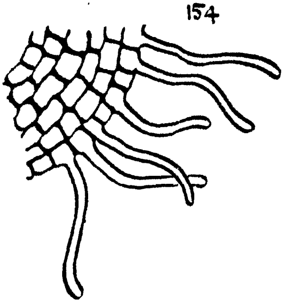


Fig. 154.—Outer edge of a young Root when cut across.

7. **Turgidity.**—If a small vessel full of sugar solution has its mouth covered with bladder and the whole is immersed in a vessel of water, we find that the bladder gradually bulges upwards by the sugar attracting more and more liquid into the smaller vessel. (Figs. 155-156.) This well represents the turgid condition of the root hair.

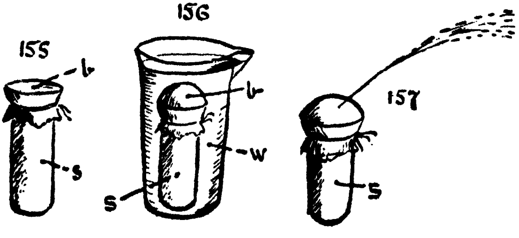


Illustration of Turgidity (*Figs. 155—157*).
An imitation of the action of a cell becoming swollen with sap.
Fig. 155.—The "cell" containing sugar solution (s.) *and closed by bladder* (b.).
Fig. 156.—The bladder bulges strongly upwards when placed in a vessel of water (w.)
Fig. 157.—The puncturing of the bladder and consequent jet of sugary liquid through the hole.

The above experiment teaches us another thing, *i.e.* that the sugary liquid is pressing outwards on the bladder. We can prove this for ourselves by puncturing the stretched membrane with a pin; a fine but forcible jet of water issues from the hole. (Fig. 157.)

When the root hair (Fig. 158, *a*) contains more sap than the cell (*b*) lying next within it, some of the sap passes through by osmosis into this cell, which becomes turgid also. This, in its turn, shares some of its sap with the next internal cell (*c*) and so on until all the soft outer cells of the root are distended with water. Some of the most internal of these cells (*d*) abut on the root's woody (or water conducting) region (*e*), and a strange thing happens when, as it were, they are full to bursting point. The living material of the swollen cells (*d*) suddenly allows the contained sap to escape into the woody region. This resembles in effect our pricking the bladder. (Fig. 157.) The water suddenly escapes from (*d*) into the wood (*e*) and so the former cells are relieved of their turgidity,

158

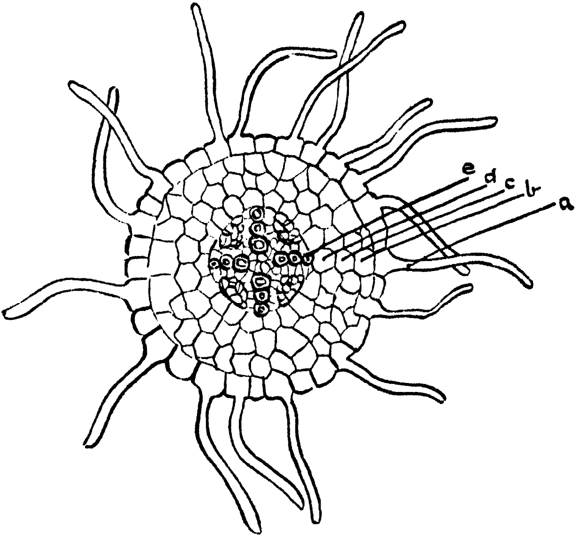


Fig. 158.—Transverse section of a young Root (*i.e.* cut crosswise.)—The woody part of the root is shown as the four arms of a cross. (For explanation of letters *a.b.c.d.e.* see the text.)

consequently being able to again take in more of the sap from the cells (*c*) lying without.

The cells (*d*) again become turgid and afterwards force their water into the wood; in fact, they are alternately turgid and flaccid, and thus rhythmically pump water into the woody region of the root. Since this woody region is continuous with that of the stem and leaves above, we see that the roots will tend to force water up the stem.

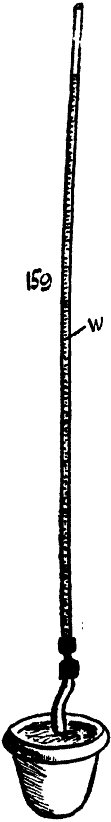


Fig. 159.—Experiment on Root pressure.

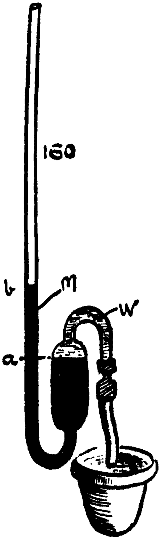
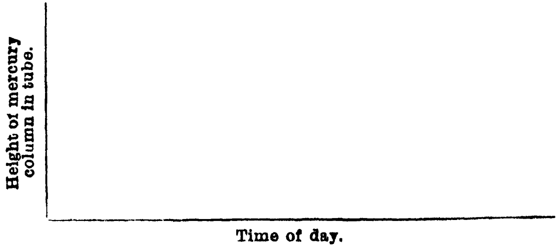


Fig. 160.—Enables us to estimate the amount of pressure in inches of mercury (*b—a*). (*m.*) Mercury; (*w.*) Water.

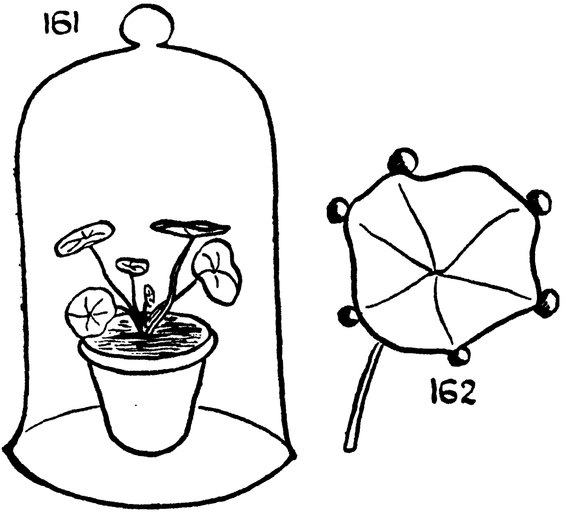
8. **Root Pressure.**—This pumping action of the roots gives rise to root pressure, *i.e.* the force with which the roots drive water up the stem. We can easily prove that roots have this power, although some plants show it better than others. Fuchsia and vine plants are very good examples. The root pressure is always stronger in spring time than any other time of the year. A small fuchsia plant will force water up an empty glass tube through a height of four or five feet. (Fig. 159.) This merely shows us that roots *do* exercise this power; it does not enable us to measure the force or to see whether it varies in intensity at different times. For this a little more elaborate experiment is necessary. (Fig. 160.) The water forced from the stem by the roots is in close contact with mercury and transmits its pressure to it. We can, therefore, measure the amount of the pressure by finding the height of the supported mercury column (*a—b*). The use of this apparatus brings to light the fact that root pressure varies in intensity at different times of the same day.

The level of the column rises

towards afternoon and then sinks again till early morning. The student should perform this experiment for himself and plot his results on a curve thus:



Another experiment also shows the presence of root pressure. A small garden nasturtium plant growing in a pot is placed under a bell jar. (Fig. 161.) First a mistiness occurs on the inner surface of the glass and afterwards small drops of water



NATURAL PROOF OF ROOT PRESSURE (*Figs. 161, 162*).

Fig. 161.—Garden Nasturtium plant placed under a bell jar.
Fig. 162.—One of its leaves, **with drops of water forced out from the end of its veins.**

appear on the edges of the leaves. (Fig. 162.) This water has been forced up the plant by the action of the roots. It appears in drops because it cannot escape into the water saturated atmosphere in the gaseous form.

9. **Absorption.**—The student will doubtless have noticed that up to now nothing has been said about the absorption of the dissolved mineral substances. The thin films of water surrounding the soil particles contain chlorides, phosphates, sulphates and other mineral salts in solution. When we consider how small a particle of soil is, and how small an amount of water will suffice to form a film over its surface, we can quite understand that only a very small amount of dissolved mineral matter is presented to each individual root hair for absorption. It is as well that this is so, for only extremely dilute solutions of mineral matters are able to enter the root hair. When we treat of water cultures later in the book, the student will note with what dilute solutions the roots are fed.

In our osmosis experiment (Fig. 153) not only was water absorbed into the funnel, but sugar passed in the opposite direction. Why did the dissolved matter pass through the membrane? Because there was relatively less of it in the water on the other side.

The ultimate result of osmosis is that there is the same strength of solution on both sides. That was why water went in one direction through the bladder and sugar in the other.

Applying this to root hair action we find that (i) some of the attractive acid substances come out from the root into the soil because they are present in the root hair and not in the soil; (ii.) That mineral substances enter the root hair because it is relatively poor in those substances. The escape of the acid sap from root hairs is nicely shown by growing a plant in a flower pot at the bottom of which a smooth slab of marble has been placed.

Examination after a month or so shows that a plan of the roots has been etched on the marble by the solvent action of the acid. These acids aid the absorbent action of the root hairs by rendering soluble some minerals which otherwise would have been insoluble. CO_2 from respiration also helps.

10. **Factors Influencing the amount of Absorption.** We will now enquire into the following questions:—

(1) What substances will roots absorb?

(2) Will they absorb these substances at equal rates? If not,

(3) What determines the rate of absorption?

Any kind of dissolved mineral substance will pass into the root hair if there be more of it in the soil water than in the sap of the root hair. The more soluble a mineral substance is, the greater will be the strength of its solution in the ground water, and hence the more rapid will be its rate of entrance into the root hair. Plants absorb all kinds of dissolved minerals presented to them, and the amount of this absorption is proportional to the solubility of the mineral. The conception is, perhaps, rather a peculiar one to grasp: a stream of water entering the root hair by osmosis, and also with this a number of dissolved minerals entering by streams of different rate.

The above is only true at the early stages of the plant's life; let us see why. The plant body consists of thousands of cells, each of which, as long as it is alive, contains sap. If the roots absorb a soluble mineral substance which is of no use to the plant, the sap of all the cells becomes choked or saturated with that particular mineral; absorption of this substance consequently ceases.

Contrast this with a useful absorbed mineral. The living protoplasm of the cells is constantly withdrawing this substance from the sap and thus making room for more to be absorbed. It follows from this that the more the cells make use of a certain mineral substance, the poorer will the sap of the cells be in that particular constituent. But since all the sap is ultimately obtained from that of the root hairs, the more impoverished will they be in respect of this mineral and the more they will absorb from without.

We may summarise the foregoing and say :—

(1) At first plants absorb all dissolved minerals in proportion to their solubility.

(2) Later they only absorb such minerals as are required for use.

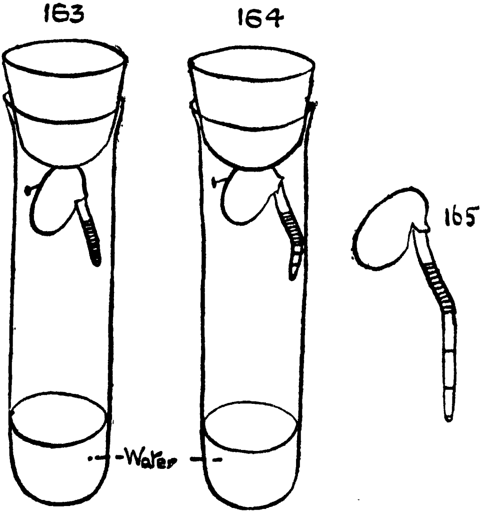
11. **Selective Action of Roots.**—From what has been said above it follows that roots "select" the materials required by the plant. The word "select" is not a good one to use, because it implies that the root possesses a reasoning power. This is not so, we know that this "selective" action is merely an outward expression, and a direct result, of the demand for certain minerals in other parts of the plant.

All plants do not utilise the same minerals in the same proportions. Farmers are well aware that wheat impoverishes the ground in silica, potatoes in potash, and beans in lime. Scientific manuring and rotation of crops largely depend upon this individuality displayed by plants. This subject will be dealt with in detail later.

12. **Region and Rate of Growth.**—The region of growth may be demonstrated by a simple experiment. A bean root

has its tip marked with a series of lines 1 mm. apart. (Fig. 163.) After a day the lines near the tip will be found to be farther apart than before (Fig. 164). This shows us that the growing point of the root is situated just behind the apex. The student will remember that this was also the part most sensitive to gravity. (Figs. 141-144.)

Do roots grow in length at a uniform rate? We can easily investigate this by germinating beans in a chimney glass.



REGION OF GROWTH OF ROOTS (*Figs. 163—165*).

Fig. 163.—A Marked Bean Root.
Fig. 164.—Is the result after 20 hours.
Fig. 165.—Is the result after 3 days.—(Note that the *actual tip* does not increase in length.)

The lengths of the roots can easily be measured by laying a metre scale parallel to them outside the glass. From obtained results, the student should answer the following questions:—

(1) Do roots grow uniformly by day and night?

(2) Does a root grow faster in continuous darkness than in alternate light and darkness?

(3) Is the rate of growth in a root affected by temperature?

SUMMARY.

A. How Root Structure Fits it for its Life and Work in the Soil.

1. ROOT CAP.—Protects delicate root tip from injury; remains of uniform thickness.
2. ROOT HAIRS.—Delicate outgrowths—clothe the region just behind root tip—their short life.
3. AGGREGATION OF WOODY TISSUES CENTRALLY.—To form a rope-like strand which best resists uprooting.
4. ORIGIN OF ROOTLET—Deep within the parent, an ideally well-protected position.

B. How Roots Absorb Water and Mineral Substances.

5. OSMOSIS.—The diffusion of water and soluble substances through a membrane until there is an equal strength of solution on each side.
6. OSMOTIC ACTION OF THE ROOT HAIRS.—By virtue of their acid sap. Note escape of sap into soil and how it aids absorption.
7. TURGIDITY.—(i.) of root hairs; (ii.) of cortex by osmosis. The most internal turgid cells pump their water into the wood vessels of the root.
8. ROOT PRESSURE.—Roots are able to force water upwards into stems. This pressure varies according to the season and the time of day. It is especially active in spring. Stems frequently "bleed" when pruned at this season.
9. ABSORPTION.—
   (*a*) of water;
   (*b*) of dissolved mineral matter in very small amounts. Rapidity and extent of absorption depends on the extent to which the particular mineral is utilised by the plant.
10. REGION OF GREATEST GROWTH in roots is just behind the tip. This is proved by marking a root with close-set lines and noting the alteration of the distances between them.

PRACTICAL.

1. Examine the roots of the floating "duckweed" for poker-like tips with sheaths resembling root caps.
2. Examine the root hairs on the roots of cress seedlings when they have been germinated on moist flannel.
3. Place sprigs of mint in water and after a few days note how the roots burst through the stems.
4. Perform the experiment on osmosis.
5. In spring set up the apparatus of Fig. 159. Do not expect immediate results. A good result should be obtained by the end of a fortnight.
6. Prove that roots grow fastest just behind the apex.

CHAPTER IX.

The Stem.

1. **Functions.**—Here, as in the root, we shall best understand the external and internal appearance of stems by studying them in connection with the work they do.

The main functions of stems are (i.) to conduct raw food materials up to the leaves; (ii.) to spread out the leaves to the sunlight in order that they may manufacture these raw materials into actual plant food, and (iii.) to conduct the elaborated foods back from the leaves to the growing points or to the storage regions.

The student should bear the above three functions in mind whilst reading the remainder of this chapter.

2. **The External Appearance of Stems.**—The outside view of stems differs very widely according as the plant in question has a life of one, few or many years. With a plant living merely one year (an annual) the stem is relatively slender, has a green colour, and is covered with a delicate transparent skin called the epidermis. Twigs of plants which live for many years have the same appearance as the above during the first few weeks of their growth. An annual plant requires to make food as rapidly as possible, so as to enable it to produce efficient seeds at the close of the season. Hence the green colour retained by the stem. This colour enables the stem to act as a food-making organ and so assists the leaves in their main work.

On the other hand, since such a plant will die down in the Autumn there is no necessity for provision to be made for protecting the stem from the rigours of winter. Further, the number of leaves to be held out to the light is very few compared with those produced on a long-lived bush or tree; we therefore find that a slender stem is strong enough to support the weight of leaves, and also that it is not necessary for the stem to branch extensively.

Any of the very numerous annual herbs will serve as an example of the above.

Some plants on the other hand live for several years, and we consequently find differences in the appearance of their stems. The green colour of the stem is replaced by a brownish tint. If we remove the protective layer from the outside of the stem we find that the former no longer possesses a membranous, transparent structure, but that it is much thicker than before. This protective coat, although it seems merely a skin, consists of a corky belt of cells lying several ranks deep. This is a good protection against cold and also it prevents the evaporation of the sap of the cells lying below. The plant thus sacrifices the food-making benefit of the stem in order to guard itself sufficiently during the winter months. The wallflower plant is a typical example.

Other differences presented by such a stem are the thicker girth and increased branching. The significance of these differences will be seen later.

Coming now to perennial plants, whose stems remain above ground many years, we find a greatly increased girth, innumerable branches, and a thick crusty bark on the exterior. All these differences in appearance are bound up with the long life of the plant. The longer the plant lives, the more sunlight is available for its leaves, and more food is made during the life of such a perennial plant than in plants living but one or a few years. Some of this increased amount of food is used in making more leaves. Since the plant is continuously the possessor of an ever-increasing number of leaves, the latter will require:—

(*a*) To be held out to the light.

(*b*) To be supplied with water and mineral substances from which they can manufacture food.

The branching of the stem is an indication of its performing the former function, whilst its increased girth shows us that it is conveying more raw materials upwards and also supporting an increased weight of branches.

If such a stem be increasing in girth its thin corky external coat will be too small for it and will be ruptured. This actually takes place, but just at the time of rupture the plant stem prepares another band of cork below. When a further thickening of the stem has taken place, this cork band is ruptured in its turn and is replaced by another corky layer produced more internally still. This goes on again and again, the bark thus becoming thicker and thicker. Examine the rugged bark of an elm, oak or elder tree (Fig. 166) and note its deep clefts. These clefts are narrower towards the trunk, becoming wider and wider nearer the outside. (Fig. 167.) It will be seen how these fissures widen year by year. At one time (an early stage) the points marked *a*—*a* were in contact. They were then burst asunder, and their rupture was followed by that of *bb* in the next year, *cc*, *dd*, *ee* in the next three years.

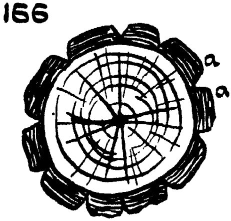


Fig. 166.—Woody Stem cut crossways to show the bark. The points (*a a*) were originally in contact.

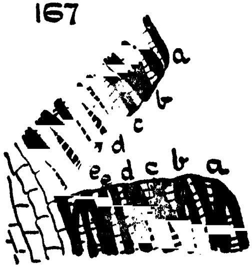


Fig. 167.—Much enlarged view of small part of the Bark in Fig. 166, showing which parts were in contact in earlier years.

It is very instructive to peer deep into the crannies of an oak tree's bark in Spring and to actually see the splitting process. Right at the bottom of the chink, the sides of which are black with age, we can see a bright yellow streak, where the actual splitting process is going on.

3. **Growth of Stems in Length.**—This again is a real necessity in order that the greatly increased number of leaves may receive a sufficient illumination.

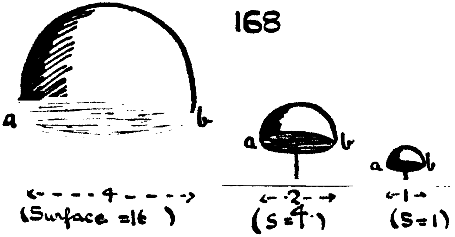


Fig. 168.—Diagrammatic illustration of the great increase in available illuminated area, consequent on elongation of a tree's branches.

We can very aptly compare the whole leaf surface of an oak tree to an ever-increasing hemisphere. (Fig. 168.) The diagram in Fig. 168 does not, however, give us an adequate idea of the tremendous increase in available illuminated area consequent on an increased diameter of a tree from tip to tip of its branches. If the diameter (*a* to *b*) increase twice, the area illuminated from above and from the sides increases fourfold; if it increase four times, the illuminated region is increased sixteen-fold. It can be seen from this what an advantage it is to the plant for the stems to increase in length. This they do by means of the buds which are always found at the tips of stems. Fig. 169 shows us in a very diagrammatic fashion the necessity for something further.

We have in *A* a small plant whose branches *c* are sufficient for holding out leaves in such a way as to utilise all the available light. When, however, the buds at the ends of these branches have caused an increase in their length as in *B*, we find a considerable amount of the light not being utilised (*i.e.* that which falls upon the spaces *a a* between the branches). Hence the necessity for buds being produced on the sides of the main branches so that they may in their turn develop into smaller branches *b b*, the leaves of which will utilise the light falling through the gaps *a a*.

169

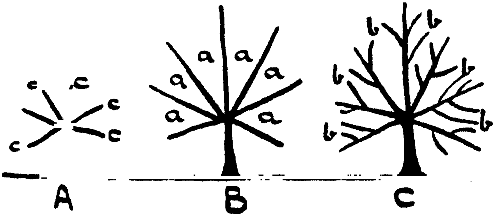


Fig. 169.—Showing the necessity of lateral branches.

We thus find buds in two positions on stems:—

(*a*) End buds, to continue the growth of the same stem in length.

(*b*) Side buds, to produce new branches so that no light may be lost.

The shade under a leafy tree shows us how well the branches perform this particular work.

4. **Buds.**—In dealing with the root we noticed the delicacy of the organ in its youngest stages. The same remark applies

to stems. In its delicate growing period the stem is always in the bud condition, *i.e.* it is covered by delicate young leaves closely crowded together. We note here how buds are protected by the position in which they arise. (Fig. 170.)

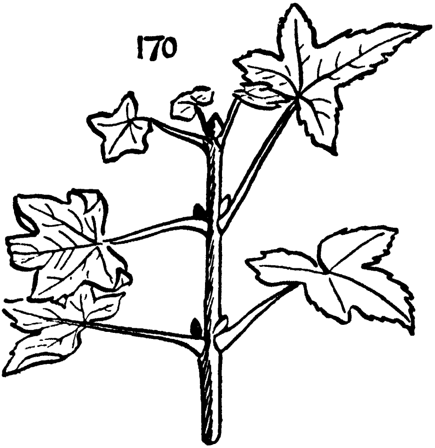
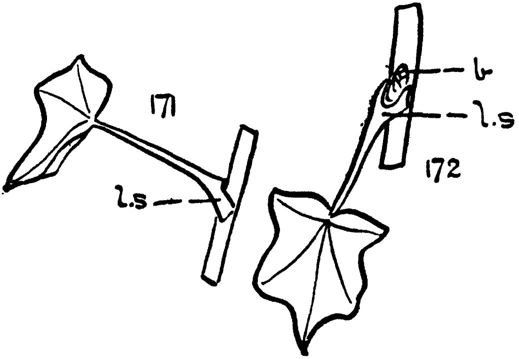


Fig. 170.—Sycamore Twig, showing protected positions of the buds.

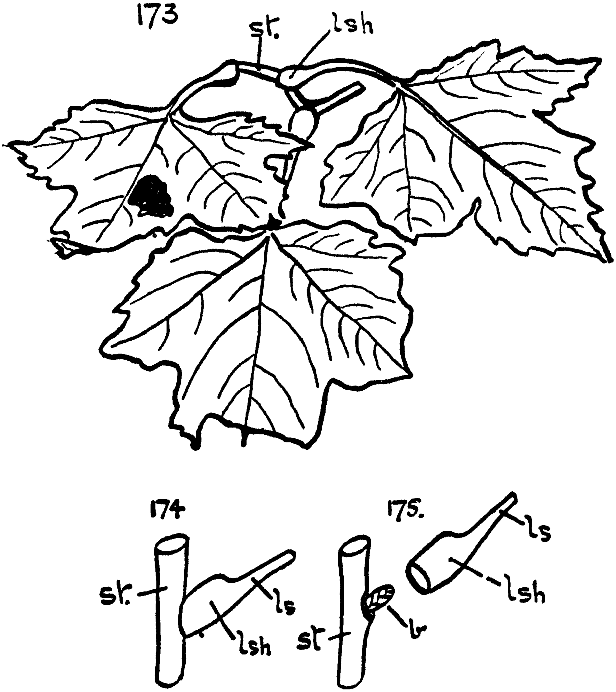
5. Their Protected Positions.—The normal position for a side bud is just within the angle (axil) formed by a leaf



Figs. 171, 172.—Protection of Bud in Ivy. (l.s.) Leaf Sheath; (b.) bud.

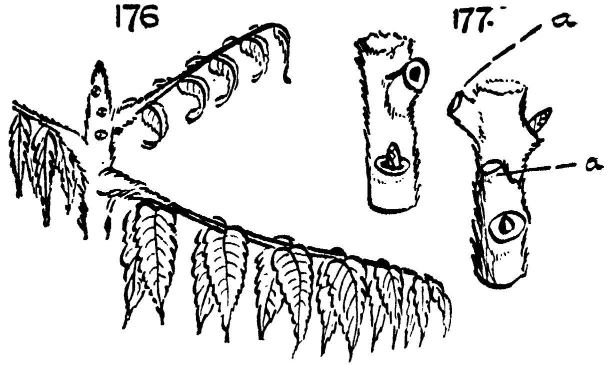
stalk with the stem. This is an ideally sheltered spot in which the bud arises, for the leaf stalk affords a protection on three sides and the main stem on the fourth side. (Fig. 170.)

There are several plants whose buds are specially well protected. In an ivy twig (Figs. 171, 172) we cannot see the buds at all. They are completely covered by a sheath at the base of the leaf stalk, and can only be seen when the latter is pulled in a downward direction. When we remember how ivy leaves remain on the plant through the winter, we can understand how the stalks of the leaves give a long protection to the buds, and thus the plant need not supply the latter with any further protection.



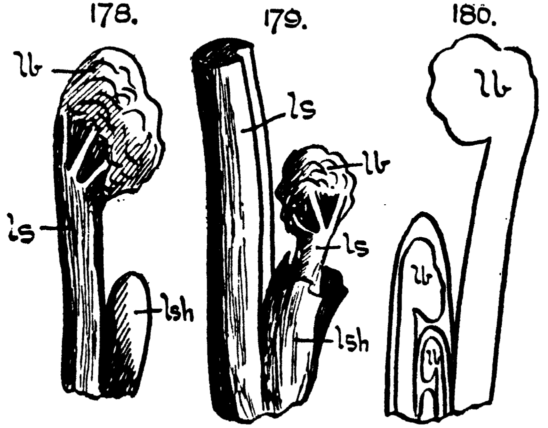
Figs. 173—175.—Protection of Bud in Plane. (*st.*) Stem; (*b.*) Bud; (*l.s.*) Leaf Stalk; (*l.s.h.*) Leaf Stalk Sheathing Base.

The plane tree (Figs. 173-175) completely envelops its buds



Figs. 176, 177.—Bud Protection in Sumach. The buds do not show at (*a a*) because the leaf stalks have not been cut across low enough.

in the leaf stalk bases. Notice how swollen these are in Figs 173, 174. Towards October the leaf can be easily detached from the stem, and we find that the base of its stalk formed a tightly-fitting case over the bud lying within. (Fig. 175.)

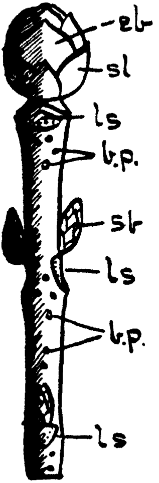


PROTECTION OF BUD IN RHUBARB (*Figs. 178—180*).
Fig. 178.—Young Leaf with its Sheath.
Fig. 179.—A Leaf bursting a Sheath from within.
Fig. 180.—Longitudinal Section of Fig. 178 showing structure of bud (3 leaves with sheaths are shown). (*l.b.*) Leaf Blade; (*l.s.*) Leaf Stalk; (*l.sh.*) Leaf Sheath.

A very similar state of things is found in the sumach tree, a plant easily recognised by the woolliness of its stems, the very many pairs of leaflets on its leaves, and the beautiful red colour these turn in the Autumn. (Figs. 176, 177). Here again no buds can be seen, but they come to view if we cut the leaf stalks across at different levels near their base. (Fig. 177.)

A very interesting bud is that of the common rhubarb. (Figs. 178-180.) At the base of the leaf stalk (*i.e.* the edible part of the plant) there is a long oval whitish case. (Fig. 178.) On opening this sheath we find another leaf, at the base of which is a second sheath. Inside this latter sheath are another leaf and sheath, and so on. (Fig. 180.) A new leaf bursting out from its protective case is shown in Fig. 179. The general arrangement of leaves and sheaths is shown in Fig. 180, where the whole structure is cut lengthways (a longitudinal section).

181.



182.

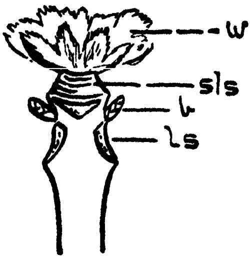


Fig. 181.—Winter condition of Horse Chestnut Twig
Fig. 182.—Dissection of a Horse Chestnut Bud.—(*e.b.*) End Bud; (*s.l.*) Scale Leaves; (*l.s.*) Leaf Scar; (*b.p.*) Breathing Places on the Stem; (*s.b.*) Side Bud; (*w.*) Woolly Hairs clothing the Foliage Leaves; (*s.l.s.*) Places where the Scale Leaves have been cut away; (*b.*) Small Bud.

6. How Buds are Protected in Themselves.—Speaking generally, we find that during the first six months growth of a bud (*i.e.* during its most delicate stage) it is protected by the base of a leaf stalk. The leaves fall in the Autumn, but by this time the bud has produced protective structures of its own. We will now examine these a little more in detail.

Nearly every bud forms an investment of thick scale leaves on its outer side. These are brown on the outside, and although much smaller than foliage leaves, they are firmer and more massive in structure. These scale leaves are well seen in Fig. 181. Plants like the horse chestnut (Figs. 181, 182) produce a further protection. They glue the scale leaves together with thick resinous material, which gives them protection against the cold. The shining appearance of these buds is due to the resinous external coat.

If we cut away all the resinous scale leaves from a horse chestnut bud, another protective contrivance is seen. The leaves and stem lying within are thickly invested with a mass of woolly hairs. (Fig. 182.) These act as a blanket in keeping the cold away from the delicate parts.

183.

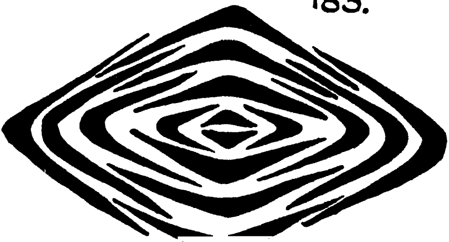
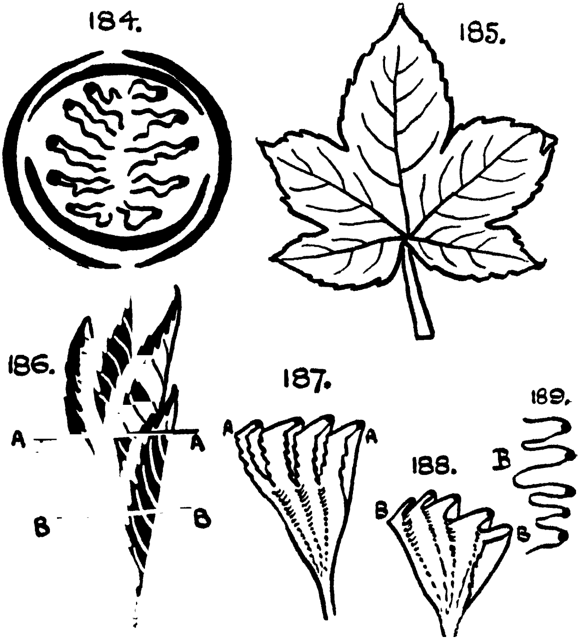


Fig. 183.—Lilac Bud cut across.

7. **Contents of Buds.**—Inside the protective layer of scale leaves enveloping buds we find the true foliage leaves packed away in a truly marvellous manner. No space is lost. The leaves are fitted close to one another, and in many cases the leaflets are folded up in various ways.

8. **Arrangement of Leaves in Buds.**—Sometimes they are crumpled up, sometimes they are quite regularly folded. If we take a bud and cut it crossways, we shall be able to see the general disposition of the leaves inside. Two of these transverse sections are shown in Figs. 183, 184. The student should bear in mind that a leaf when cut across will appear as a line because it is such a thin plate of tissue. Any thicker

part of this line will show where a large leaf-vein has been cut across. Fig. 183 gives the transverse view of a lilac bud. The leaves are in pairs, each pair at right angles to the next pair, and some sixteen leaves can be made out. Fig. 184 shows that in the sycamore bud the leaves are folded fan-wise.



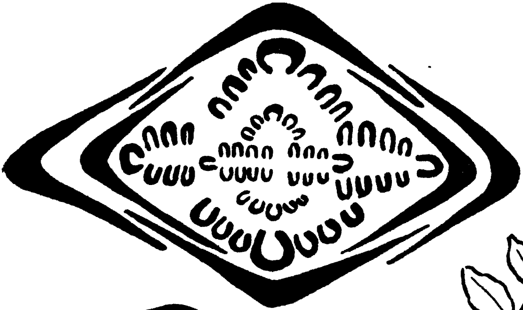
Bud Structure in Sycamore (*Figs. 184—189*).

Fig. 184.—Bud cut across.—Note difference between foliage and scale leaves.
Fig. 185.—Mature Leaf of Sycamore.
Fig. 186.—How the Leaf is folded in the Bud.
Fig. 187.—How the appearance of the Foliage Leaf in the Bud is obtained.
Figs. 188, 189.—How the Leaf would have appeared if the bud had been cut across deeper down.

Outside we have the protective zone of scale leaves, whilst within this are two foliage leaves. Apparently there are ten leaves or thereabouts, but this is not so, for if we consider the mature leaf of the sycamore, we find it has five or six chief veins, and in the bud the leaf is folded so that these veins lie parallel to one another. (Figs. 185, 186.) Since the section has happened to cut the leaf high up we have the appearance as in Fig. 187. Had we cut the leaf lower down we should have had a continuous wavy line as in Figs. 188, 189

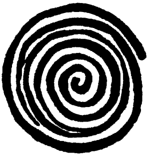
The ash bud shows us a somewhat similar arrangement, but here four pairs of foliage leaves can be seen. (Fig. 190.) The

190.



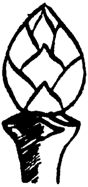
191.

192.

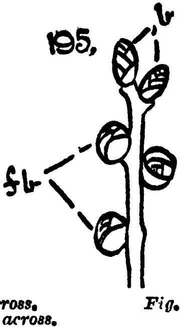


193.

194.



195,



196.

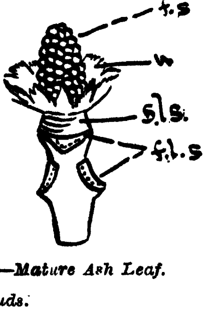


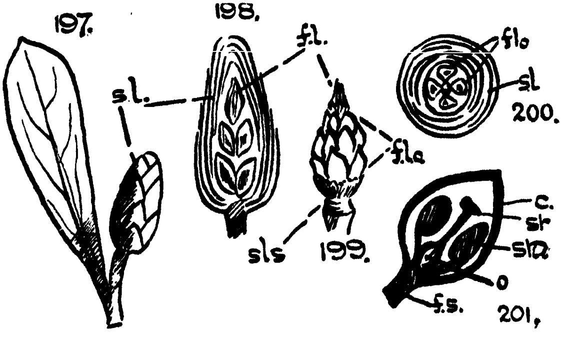
Fig. 190.—Ash Bud cut across. *Fig. 191.—Mature Ash Leaf.*
Fig. 192.—Wheat Bud cut across.
Figs. 193, 194 —Varying shapes of Horse Chestnut Buds.
Fig. 195.—Various shaped Buds of Elm.—(*b.*) Leaf Buds; (*f.b.*) Flower Buds.
Fig. 196.—Dissected Bud of Horse Chestnut.—(*f.s.*) Spike of Flowers; (*w.*) Woolly Leaves; (*s.l.s.*) Scale Leaf Scars; (*f.l.s.*) Foliage Leaf Scars.

mature foliage leaf of the ash has many pairs of leaflets. (Fig. 191.) Each leaflet in the bud is folded on itself in a similar way to the parts of the sycamore leaf.

In wheat and other grasses (Fig. 192) the leaves are coiled round one another in a close spiral. We noticed this construction in connection with the germination of maize, wheat and barley. For demonstration to a class of school children a cabbage or lettuce shows bud structure on a very large scale. In either of these there is a short stem closely clothed with leaves which are more and more delicate and more adequately protected the nearer they lie to the stem itself.

9. **The Presence of Flowers in Buds.**—This may come as a surprise to some readers, but a moment's reflection as to the early flowering of some of our British plants will lead one to see that it will be most probable that such plants will form rudiments of flowers in their buds, so that they can be unfolded at the earliest opportunity in the Spring.

The horse chestnut bud may be oval or more globular in shape. (Figs. 193, 194.) We shall most probably find flowers in the latter but not in the former variety. The globularity of buds is frequently an indication of flowers within. Contrast the shapes of the buds shown on the elm twig. (Fig. 195.) The roundish buds here contain flowers whereas the longer variety contain only leaves. Returning to the horse chestnut bud, we find, on cutting away the sticky mass of scale leaves



Figs. 197—201.—Structure of a Rhododendron Bud.
Fig. 198.—Bud cut down.
Fig. 199.—Scale Leaves removed from Bud.
Fig. 200.—Bud cut crossways.
Fig. 201.—Flower cut lengthways.—(*s.l.*) Scale Leaves; (*f.l.*) Foliage Leaves; (*s.l.s.*) Scale Leaf Scars; (*f.l.o.*) Flowers; (*c*) corolla; (*st.*) Stigma; (*sta.*) Stamens; (*o.*) Ovary; (*f.s.*) Flower Stalk.

and separating the woolly foliage leaves, that a fluffy cone-like structure remains centrally. (Fig. 196.) If the bulk of the fluffy hairs be removed with a needle we can discover that the whole cone is covered with tiny globular rudiments of flowers. The cone will expand in the Spring to form the large spike of pink and white flowers which sometimes reaches a length of ten inches or so.

Another bud well worth dissecting is that of the rhododendron. Its structure is fully indicated in Figs. 197-201. In this bud the flowers are so large that their structure can be easily investigated with a hand lens. Fig. 201 gives a longitudinal section of one of the flowers.

10. **Shapes of Buds.**—Winter is the time for bud examination. It is a very good plan to take a walk through a wood merely to examine the variously shaped buds which characterise our forest trees. Oak will be found to have short "squat" buds, whilst the other extreme will be found in beech buds. (Fig. 202.) The student should draw these carefully and note in each case the texture, shape, and number of the investing scale leaves, as also the number and character of the foliage leaves which are discernible.

202.

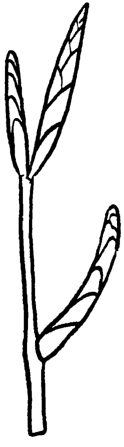
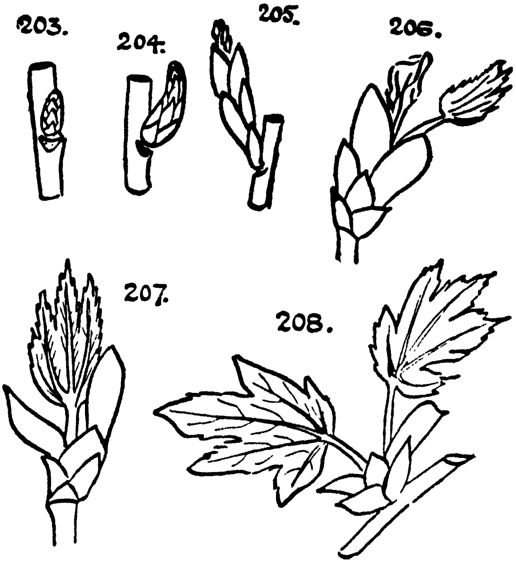


Fig. 202.—The long Buds of Beech.

11. **Elongation of the Stem.**—The more interesting part of our work consists in keeping particular buds under observation at the time of their bursting in Spring. The main points noticeable are: (1) the separation and sometimes the immediate fall of the scale leaves; (2) the great and rapid increase in size of the blades of the foliage leaves; (3) the sudden elongation of their hitherto short leaf stalks; (4) the straightening out of the broad leaf surfaces from their folded form; and (5) the increase in growth of the stem itself. Successive stages like those of sycamore (Figs. 203-208) should be drawn and compared.

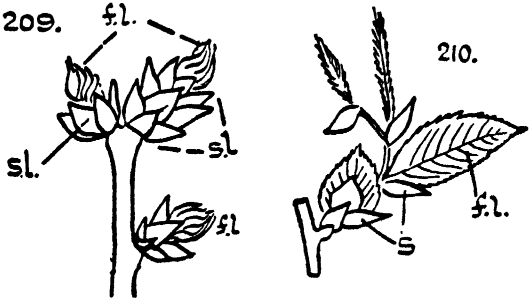
The bursting of lilac and elm buds is shown also in Figs. 209, 210.

12. **Examination of Scars found on Woody Stems.**—An ideal way is to mark one particular twig by tying a string round it and to observe the development of this one twig for several years. The student will then be easily able to read the scars found on old stems.



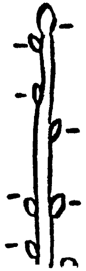
Figs. 203—208.—Successive stages in the opening of a Sycamore Bud.

Whenever a bud throws off its scale leaves we find that a circle of ring-like scars is left on the stem. This enables us to decide how much of the length in an old stem has been added on in any particular year.

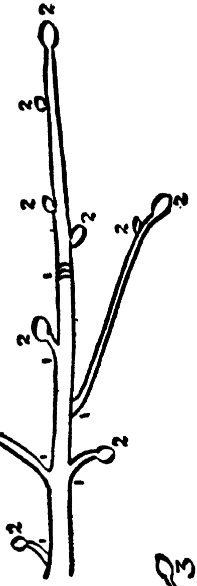


Figs. 209, 210.—Opening Buds of Lilac and Elm respectively. **(*s.l.*) Scale Leaves; (*f.l.*) Foliage Leaves.**

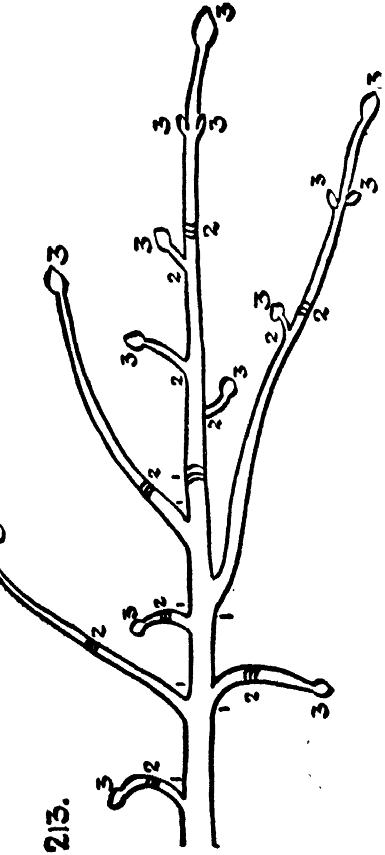
211.



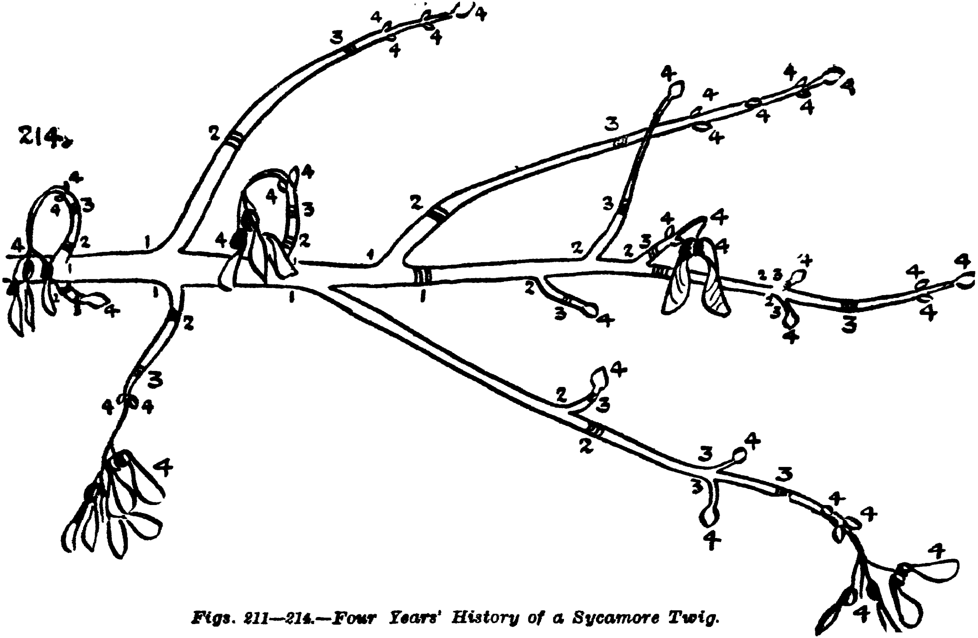
212.



213.



214



Figs. 211—214.—Four Years' History of a Sycamore Twig.

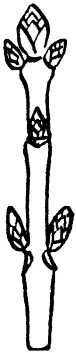
13. The History of a Branch.—The four Figures, Nos. 211 to 214, showing the winter condition of the same sycamore twig will repay the most careful study.

Table of Explanation of Figs. 211-214.

Fig.	Year.	Length of Stem Produced :—	This Length by Growth of Buds.	Side Buds Produced :—
211.	1st Autumn	From 0 to 1.	Terminal bud 1	Those marked 1.
212.	2nd Autumn	From ringscar 1 to end bud 2, side branches from 1 to buds 2 at ends of short branches.	By all the buds marked 1 in Fig. 211.	Those side buds 2 situated on the new length of main stem.
213.	3rd Autumn	In main stem and larger branches from ringscars marked 2 to end buds marked 3.	By all the buds marked 2 in Fig. 212.	The side buds marked 3 (1 pair seen in the main stem and 1 pair in the largest branch).
214.	4th Autumn	All increased length of stems from ringscars marked 3 to the end buds 4 or to the groups of fruits 4.	By all the buds marked 3 in Fig. 213.	All the side buds marked 4. These are shown in the majority of the branches.

The ring scars in the above Figures must not be confused with the scars of the foliage leaf stalks. (Fig. 215.)

215.



216.

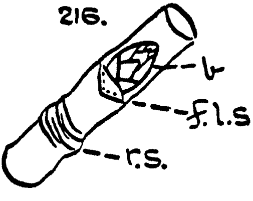


Fig. 215.—Winter condition of a Sycamore Twig.
Fig. 216.—Small portion of a Twig to show the 2 kinds of scars.
(*r.s.*) Ring Scar; (*f.l.s.*) Foliage Leaf Scar.

Just below each side bud on the stem we find the horseshoe-shaped scar of the leaf stalk. Fig. 216 shows the two kinds of scars on the same twigs, so that no difficulty will be experienced in distinguishing one from the other.

One thing especially noticeable from Figs. 211-214 is that relatively few branches are produced. The specimen from which Fig. 214 was drawn had 135 leaf scars but only 57 buds or branches. Many evidently had been destroyed, since traces of them could be seen. On the other hand, some had remained in a quiescent or dormant condition and had not developed.

A plant does not develop all its buds into branches at once. It is interesting to note that many of its buds only develop when an accident has stopped the growth of other buds.

SUMMARY.

Main Functions of Stems.

(*a*) To hold leaves out to light.
(*b*) To conduct water and minerals to the leaves.
(*c*) To conduct food from the leaves.

General Appearance of Stems in Plants.

A. LIVING ONE YEAR.	B. LIVING FEW YEARS.	C. LIVING MANY YEARS.
Slender.	Stouter.	Very thick.
Green.	Brown.	Frequently black.
Little branched.	Branched to a greater extent.	Much branched.
Covered with epidermis.	Covered with cork.	Covered with bark.
Bears relatively few leaves.	Bears more leaves.	Bears thousands of leaves.
Juicy texture.	More woody.	Very woody indeed.

Buds by their growth enable a greater illuminated area to be utilized by the leaves.

Protection of Buds.

1. POSITION: In angle between leaf stalk and stem.
   Special contrivances in ivy, plane, sumach, rhubarb.
2. PROTECTIVE STRUCTURES IN BUD ITSELF.
   (*a*) Scale leaves (nearly all buds).
   (*b*) Resin. (Poplar, horse chestnut).
   (*c*) Hairs. (Horse chestnut, willow).

Some buds contain flowers as well as leaves. (Horse chestnut, rhododendron).

Packing of Leaves in the Bud.

Leaves either folded or crumpled.
No space is lost in a bud.

Yearly Growth of Stems in Length.

Stems show two kinds of scars.
- (*a*) Scars where leaf stalks have fallen.
- (*b*) Scars where bud scales have fallen.

Therefore bud-scale scars enable yearly growth to be traced.

In any one Year.

- (*a*) The end bud elongates.
- (*b*) The side buds grow out into branches.
- (*c*) New buds are formed on both main stem and side branches.

PRACTICAL.

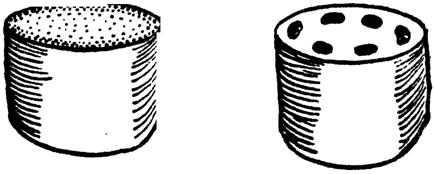
1. Examine the branching of forest trees.
2. Draw the distinctive shapes of forest trees.
3. Note differences in shapes of the same kind of tree when grown—
    - (*a*) In the open.
    - (*b*) In a close copse.
4. Examine and draw as many buds as possible.
5. Examine the stems of any woody plant for leaf scars and bud scars.
6. Keep some opening buds under observation and draw successive stages.
7. Reconstruct the previous appearance of a stem for several years past on the evidence afforded by its scars.

CHAPTER X.

The Stem as a Conducting Organ.

How the Internal Structure of Stems Fits them for their Work.—We have dealt with the importance of the stem as a water and food conducting organ in the previous chapter and noticed that *one* reason for stems growing thicker as they grow older was that they might convey more water up to the leaves.

It now remains for us to examine the conducting tissues more in detail. In soft juicy stems they are found in the form of strings or threads known as vascular bundles. The juicy stalk of a cabbage shows these vascular bundles very plainly indeed, but we can observe them in young stems as dots on the cut surface. (Figs. 217, 218.)



217. 218

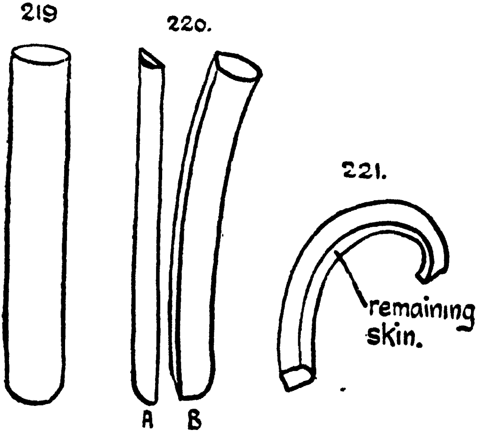
Figs. 217, 218.—The arrangement of the Vascular Bundles in Stems, possessing one Seed Leaf (*Fig. 217*); two Seed Leaves (*Fig. 218*).

1. **Arrangement of the Vascular Bundles in Green Stems.**—The disposition of these conducting strands varies in different plants. In plants like maize, barley, wheat, which

have but one seed leaf in their seeds, we find the vascular bundles dotted all over the cut surface of the stem (Fig. 217), but in young stems of those plants which have two seed leaves the conducting strands are always arranged in a ring. (Fig. 218.)

2. **Use of the Soft Region in Green Stems.**—All the rest of the stem (except the outermost skin or epidermis) is soft and juicy, and consists of thin-walled cells swollen out with sap. It is the swollen condition of these cells which gives a rigidity to the green stem, for the surface skin or epidermis tends to prevent them from swelling, and is thus made taut and stretched.

The student may compare the rigid condition of a young stem produced by its swollen internal tissue and its restraining stretched epidermis with the firmness of an inflated football, produced by the swollen bladder within and the restraining taut case outside. That the skin of a young stem is stretched and that its internal tissue is compressed can easily be proved by experiment. A part of a young elder stem, free from leaves (Fig. 219), was taken and carefully measured. Its length was 21·9 cms. The outer skin was then cut off strip by strip with a sharp knife. On the removal of the first strip, the stem was found to have curved over slightly in the opposite direction.



TENSIONS IN TISSUES (*Figs. 219—221*).
Fig. 219.—Complete Elder Stem.
*Fig. 220.—*A. *A strip of skin removed from the Stem* B.
Fig. 221.—All the skin removed but one strip.

(Fig. 220B.) When all the skin had been removed except one strip (Fig. 221), the stem had a very pronounced curve indeed over towards this remaining strip of skin. On removing this last strip, the whole of the central mass was exceedingly flabby, and had lost some support. But the strips of skin were equally flabby. Evidently, then, neither central region nor skin afforded any intrinsic support *per se* but only when both were present.

To prove the matter conclusively, the lengths of the central region and the detached skin were measured accurately, and were found to be:—

(*a*)	Central region	22·8 cms.
(*b*)	Skin strip	21·6 cms.

Now the original length of the complete stem was 21·9 cms. When freed from the skin the central soft mass was longer than before; whilst the separated skin was shorter than before. The only explanation is that the skin was restraining the swelling of the central region with sap, and was itself being stretched in consequence. These two actions—compression and tension—are therefore mutual and inseparable, and to them we owe the rigidity of succulent stems. This has an important bearing on the life of annual plants, which have not the food at their disposal from which to manufacture rigid woody stems, and yet have to hold out their leaves to the light.

3. **Dual Nature of the Conducting Tissues.**—For the student thoroughly to understand the necessity for there being two kinds of conducting tissue in stems, and in other plant members in addition to stems, we must slightly anticipate a later chapter, where food manufacture is treated fully.

Stems conduct water by their wood to the leaves, so that the latter may make sugar. This sugar is not retained in the leaves, for it is not all required there. It may travel back by osmosis through the soft cells of the leaf into the cells of like nature comprising the bulk of the stem, and from these it may travel up or down the stem according to necessity. The sugary substances always travel in this slow, oozing fashion *through the juicy cells* of the plant.

We did not call this region a conducting tissue in the earlier paragraphs of this chapter, because the cells comprising it are not obviously lengthened into conducting pipes or tubes; nevertheless, soluble carbohydrates are always conveyed thus, and so, strictly speaking, the softer regions of stems *are* conducting tissues.

We investigated in an earlier chapter the chemical character of protoplasm, and found it to contain sulphur and nitrogen.

These latter substances ascend the woody parts of stems in the form of sulphates and nitrates dissolved in the water. The plant needs to combine these mineral salts with sugar before it can have any new proteid food. It is an open question as to where this synthesis takes place, but there is no doubt whatever as to the path along which the nitrogenous food-stuffs travel when once they have been elaborated.

Lying alongside the woody conducting strands we find another conducting region called the bast or phloem. The walls of the bast tubes are much softer in texture than those of the wood, and so they are more easily overlooked.

Nitrogenous foods always travel through the bast tubes, whether they are going up the stem to form new living matter in the regions of the buds, or in a downward direction for storage or general nutrition purposes.

4. Summary of the Conducting Tissues.

GENERAL TEXTURE.	NAME.	LENGTH OF CELLS.	MATERIALS CONVEYED.	DIRECTION.
Hard.	Wood (Xylem)	Long, tubular.	Water. Mineral salts.	Upwards.
Soft.	Bast (Phloem)	Long, tubular.	Nitrogenous substances.	Upwards or downwards.
Soft.	Juicy Cells.	Short.	Sugar.	Upwards or downwards.

5. Detailed Examination of the Wood and Bast.—We must call in the help of the miscroscope here, since the

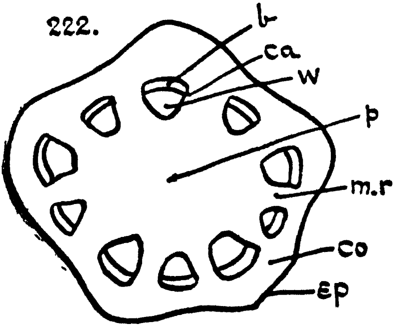
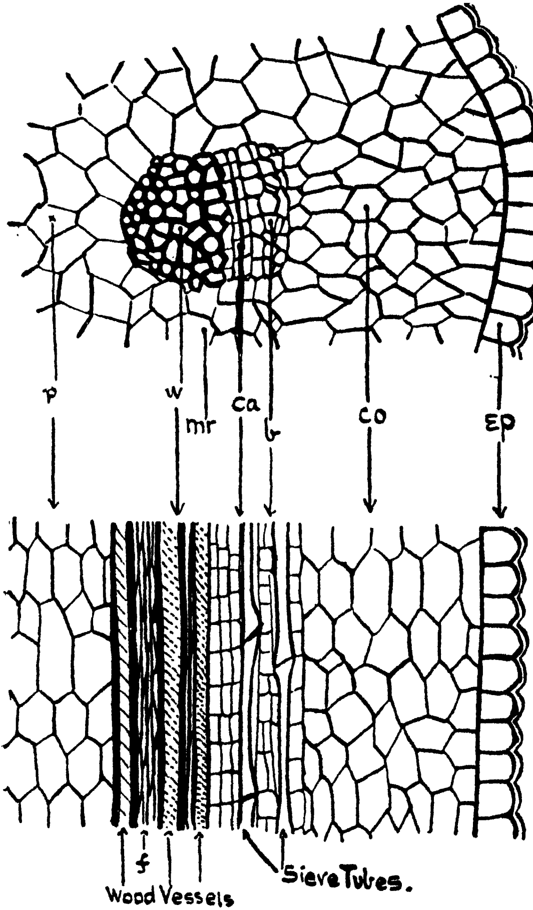


Fig. 222.—Transverse section of a young Wallflower Stem, showing arrangement of tissues.—(*b.*) Bast; (*ca.*) Cambium; (*w.*) Wood; (*p.*) Pith; (*m.r.*) Medullary Ray; (*co.*) Cortex; (*ep.*) Epidermis.



223.

224.

Figs. 223, 224.—Enlarged view of a bundle and adjoining tissues from a young Wallflower Stem. (References as in Fig. 222).

individual cells are much too minute to be seen otherwise. The general arrangement of the woody parts has already been seen in Fig. 217, 218. A young wallflower stem, much magnified, is shown in Fig. 222.

We see the ring of vascular bundles embedded in the softer cells, and the surface skin of cells surrounding the whole. The softer cells or parenchyma constitute (1) the pith in the centre of the stem, (2) the medullary rays lying between the vascular bundles, and (3) the cortex lying between the vascular bundles and the epidermis. Each vascular bundle consists of two parts:—

(*a*) The inner hard woody part;

(*b*) The outer soft-celled bast region. (Fig. 223.)

In this more detailed view, notice the large vessels of the wood, and also the rather large tubes (sieve tubes) of the bast. It will be seen that these two kinds of cells do not comprise the whole of the vascular bundle. We find fibres and other cells packed in between them. These, as also the wood vessels and sieve tubes will be much better seen in a view of the stem cut lengthways (longitudinal section, Fig. 224). The student should note particularly the length of the wood vessels and the sieve tubes. This by itself is a strong indication of their conducting function. The sieve tubes get their name from perforated areas (sieve plates) in their walls, which allow the passage of the nitrogenous food stuffs. Two of these sieve plates are shown in Fig. 225.

225.

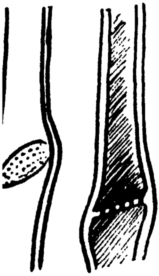


Fig. 225.—Sieve Tubes showing their Sieve Plates.

The long fibres (*f*) seen dovetailing into one another in Fig. 224 are not conducting in function, but give a mechanical strength and support. Indeed, the supporting function of the wood is only second in importance to its value as a water-conducting region.

We have left unmentioned one part which may seem very insignificant in itself, but the importance of which in the later life of the stem cannot be over-estimated.

This is the thin band of soft cells lying in each vascular bundle between the wood and the bast. It is known as the Cambium, and to its activity is due all the later growth of the stem in girth. (Figs. 227, 228, 231-233.)

6. Necessity of Increase in Girth of Stems.—From what has been said previously concerning the water-carrying function of the wood, the student might form a very erroneous opinion on examining the cut surface of any felled tree. He might think that the wealth of wood has been formed for the sole purpose of supplying the leaves with more water. This is a wrong conception. The falsity of this was strongly brought home to the writer when in Nithsdale a few months ago. An oak tree had been recently felled and its stump was found to be "bleeding" every morning in the peripheral region of the wood. The bulk of the wood in the centre of the tree was always quite dry. (Fig. 226.) Later in the day the phenomenon was not noticed because of the sun's drying action. This clearly showed one very important fact: only the wood lying just within the bark conducts water upwards. This is the sap wood; the central, dry mass of wood (the heart wood) merely subserves a mechanically supporting function. Of course, as a stem increases in girth, it necessarily follows that the sap-wood increases in amount, since it lies on an ever-increasing circumference, but the biological necessity underlying the great increase in girth in a stem is the fact that an ever-increasing mass of branches has to be supported. These branches we have already seen to be absolutely necessary in order that the increased number of leaves may be presented to the light.

226

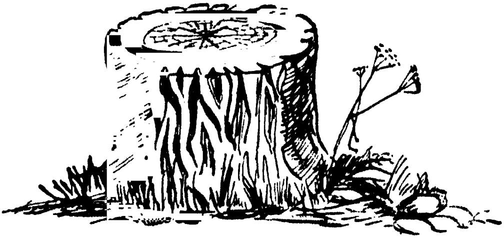


Fig. 226.—"Bleeding" of an Oak Trunk.—The black part of the cut surface of the wood was the only part from which water oozed.

The main function of a trunk-like stem, therefore, is supporting, whilst the conducting work is limited to, and adequately performed by, that wood which lies nearest the bark.

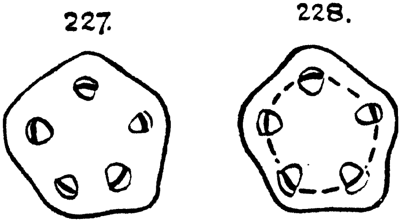
7. Mechanism by which Stems Increase in Thickness.—We have already noticed the soft juicy living cambial cells lying between the wood and bast in the bundles of a young stem; *the adjective "living" is introduced here in contrast with the dead vessels of the wood.*

Whether the wood vessels be full of water in the sapwood or whether they be full of air in the central heartwood, they are all alike in that they contain no protoplasm. We might very well term them "cell skeletons," and not cells. The same remark applies to the long strengthening fibres scattered throughout the wood.

Why should the thin layer of living cells lying between the wood and bast be so important? Because *it retains for many years the power exhibited so strongly by the cells situated at the growing tips of the branches:* the wonderful power that cells have of dividing and so producing new daughter cells.

The student should reflect for a moment on the thousands and thousands of new cells that must be produced by those few energetic cells lying at the tip of the stem of an oak seedling before an ancestral tree is produced.

The delicate cambial cells in the vascular bundles retain this generative power and give rise to new cells, both towards the pith of the stem and also towards its outer side. Fig. 227 clearly shows that these cambial regions all lie on the circumference of the same circle in the transverse section of the stem. The soft cells lying on the other parts of this circle (Fig. 228, dotted line) also exhibit a similar activity and give rise to new cells both within and without. We now have a continuous circle of actively dividing cells. This is in transverse section, but if we



THE FORMATION OF A COMPLETE CAMBIAL RING
(*Figs. 227, 228.*)

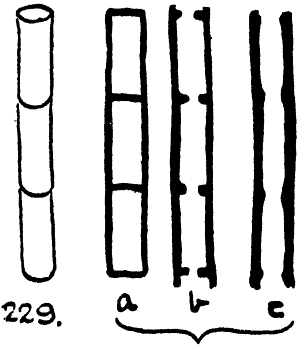
Fig. 227.—The Cambium shown as a dark line traversing the Vascular Bundles.

Fig. 228.—The completion of the ring by cells lying along the dotted line becoming cambial in function.

consider the position of the cambium through the stem's length, it will evidently be in the form of a *hollow* cylinder. As this cylindrical cambium produces more and more cells on its inner side, it becomes a cylinder of ever-increasing diameter.

The daughter cells produced on the inner side grow very greatly in length. They may remain thus as long fibres or their *end* walls may be absorbed so that long continuous tubes or vessels are formed. (Figs. 229, 230.) Lastly, their walls are changed from thin delicate cellulose to thick resistant woody material, and thus more wood is added to the continuously-thickening stem.

The cambium produces a far greater number of cells on its inner than on its outer side. Some of those produced in the latter position elongate to form the fibres and the sieve tubes of the bast, but their soft cellulose walls are not converted into wood. The process of thickening is shown in Figs. **227**, 228, 231-233. These will repay a careful study.



229.

230.

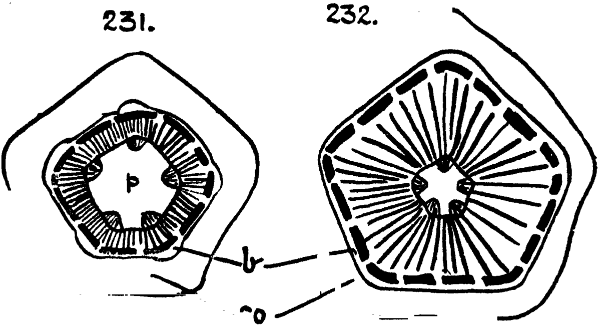
THE FORMATION OF VESSELS (*Figs. 229, 230*).

Fig. 229.—Three cells above one another.

Fig. 230.—(a.b.c.) Three lengthwise views to show gradual absorption of the crosswalls.

8. **Annual Rings.**—In Spring a cracking of the bark takes place, and this relieves the pressure on the internal tissues. In addition the root-hairs below ground are specially active in absorbing water in spring, and root pressure is then at its maximum intensity. There is thus an abundant flow of sap up the tree. At this time the cambial cells are able to make large new cells, for there is plenty of sap with which the cells may be swollen out, and also they may more easily swell out since the pressure of the bark has been relieved. As a consequence we find that the wood vessels formed in spring are of a large calibre.

In Autumn there is less sap available and also the bark has been strengthened prior to the oncoming of winter, and we find that the wood produced at this season is much closer in texture than the spring wood. In fact it consists very largely of long, narrow, thick-walled fibres. The difference in the texture of these alternating spring and autumn woods gives the well



Figs. 231, 232.—Thickening process in Woody Stems.—The wood is shaded with radiating lines. The Cambium is figured as a thick interrupted line. Outside it lies a thin layer of Bast *(b.)*, *(co.)* is the Cortex. Later in the thickening process, very much of the cortex is cut off in the formation of bark.

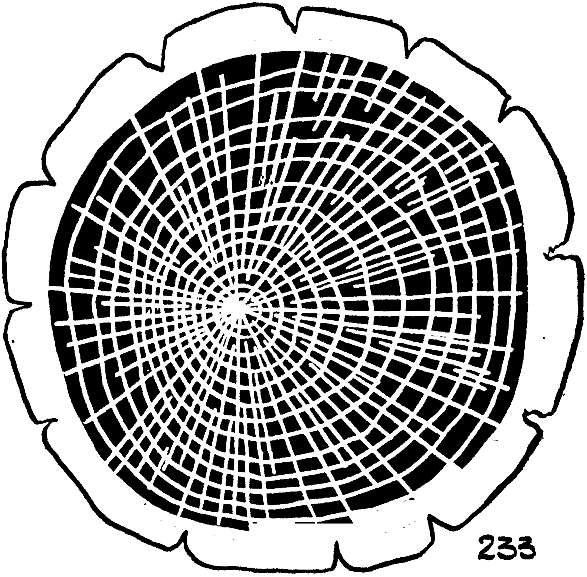


Fig. 233.—Transverse section of a Tree Trunk showing annual rings and medullary rays.—The thick black line is the cambium and the bast. How old was the tree when it was cut?

known appearance of the annual rings. (Fig. 233.) From them it is easy to calculate the age of the tree trunk. A detailed view of the gradual change in character of the wood produced in two years or so is given in Fig. 234 (See also Micro-Photograph on page 277).

9. **Medullary Rays.**—We have, for simplicity, spoken as though all the cells produced by the cambium turned into wood or bast, but this is not so. The long whitish streaks found radiating from the pith of a trunk to the bark consist of cells which have not been altered. They remain as juicy living cells and constitute the medullary rays. Just a few of these may be traced from the pith to the bark, but the bulk of them are much shorter. They seem to start at any point in the wood and traverse the latter for variable distances. (Fig. 233.) Figs. 234-236 will make clear that these medullary rays are merely bands of cells and not continuous sheets running throughout the whole length of the stem.

234.

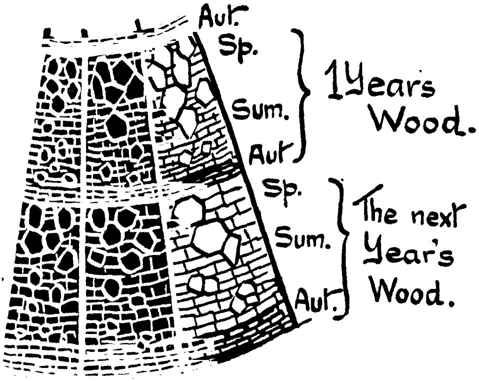


Fig. 234.—Two years' growth of wood in a Lime Tree.—The large cells are the vessels, the smaller ones are the wood fibres. Four medullary rays are shown.

10. **Extent of Living Tissue in Stems.**—All the wood proper (vessels and fibres) is composed of dead cell walls. Similarly the bark is dead because its waterproof nature cuts it off from food. There only remain the cambium and the bast (excessively thin layers lying just within the bark) together with the medullary rays which consist of living tissue.

11. **Use of the Medullary Rays.**—Examination by the microscope shows us, especially in autumn-gathered material, that the cells of the medullary rays frequently contain starch grains. This points to a storage function. They form a convenient near storehouse of the food required by the next season's developing stems and leaves, since by their use it is unnecessary for the plant to convey such nourishment right down the stem to underground storage regions and then back again the same long distance when required. Fig. 236 shows starch grains contained in the cells of the medullary rays in a woody stem.

235.

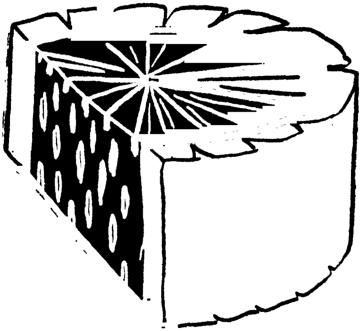


Fig. 235.—Diagrammatic illustration that the medullary rays are only short bands of cells.

Instead of microscopic examination, the presence of starch may be shown by dipping the cut end of a branch into iodine solution. In a short time the rays turn a dusky bluish-black colour, the woody parts of the stem being stained a yellowish brown by the fluid.

236.

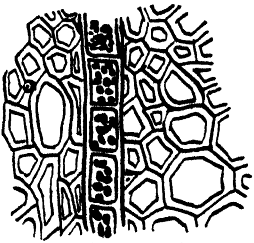


Fig. 236.—Storage of Starch Grains in the cells of a medullary ray of a Sycamore Stem.

12. **Origin of Knots in Wood.**—It very frequently happens that branches are snapped off from trees by animals or by the wind. Often in these cases a small part of the branch

is left attached to the tree. This forms a "knot" by becoming embedded in the wood formed later by the cambium. The facts that a "knot" is very easily dislodged from the wood of the plank in which it is found and that it is very often of a different colour from the surrounding wood show that it was produced at a different time from the other wood and that it had no immediate organic connection with that wood. The decay of the bark of the knot also aids the ready removal of the latter from the later formed wood. The extremely hard character of the wood forming a knot is explained by the pressure to which it has been subjected by the surrounding wood, and later by the bark from without.

13. **Healing of Wounds on Stems.**—The student should examine the pruned parts of trees month by month and note how a projecting circular growth from the cambium ring covers this essentially living part, and later creeps, as it were, over the outer region of the wood, in order to close those vessels (*i.e.* the sap wood) that would otherwise "bleed" and cause a loss of sap to the tree. If the wound be a lateral one, as caused by a slash of a knife, the outgrowth from the cambium often completely fills the gap. This projecting outgrowth becomes dark coloured and corky.

It is worth noticing how readily young buds are produced from the living part immediately below this protective scar. This can be particularly well seen in lime trees. The bursting of a pollarded willow into new life is well worthy of a close study in this connection.

SUMMARY.

The Internal Structure of Stems.

Soft green stems are made rigid by tensions in their tissues. Old stems are made rigid by the great development of wood.

The Conducting Tissues.

Soft celled tissues conduct sugar.

Wood conducts water and mineral substances.

Bast conducts nitrogenous food stuffs.

Main Conducting Elements.

(*a*) Wood vessels (in the wood) of the vascular bundles.
(*b*) Sieve tubes (in the bast) of the vascular bundles.

Why Stems Grow Thicker.

(*a*) To give greater support.
(*b*) To conduct more water.

Arrangement of the Vascular Tissues.

(*a*) Grass-like plants:—Very many small scattered bundles.

(*b*) Many green stems:—A ring of vascular bundles.

(*c*) Woody stems:—A solid mass of wood surrounded by a thin band of bast.

How the Increase in Thickness Takes Place.

The cambium becomes a hollow cylinder between wood and bast.

It produces many new cells on both sides.

The inner cells are transformed into wood, the outer into bast.

Annual Rings

Are produced by difference in texture of Spring and Autumn wood.

Causes of this.

In Spring much sap and less bark pressure. In Autumn *vice versâ.*

Medullary Rays

Are radial strands of cells remaining living and unaltered in the woody region.

They are functional as storage reservoirs.

Amount of Living Tissue in Woody Stems.

Only the bast, cambium and medullary rays.

The wood and bark are both dead tissues.

Knots are dead branch bases which have become embedded in more recent wood.

Healing of Wounds on Stems.

By protective outgrowth from the cambium region.

Such outgrowths soon develop into cork masses.

PRACTICAL.

1. Perform the tension experiment with a piece of elder stem and verify the figures quoted in the text.
2. Examine the cut surfaces of sunflower and any other green stems. Draw the arrangement of the vascular bundles. Decide whether the plant has one or two seed leaves in its seed.
3. "Ring" a branch of a tree (*i.e.* remove a ring of all soft tissues down as far as the wood). Examine for several days to see if the leaves flag.

4. Treat another branch similarly, but cut through the sap wood as well. Explain the results.
5. Examine and draw the cut ends of tree trunks, name all the parts seen.
6. Calculate the age of trees by counting their annual rings.
7. If possible examine a freshly felled tree for sap wood and heart wood.
8. Cut a branch from a tree in Spring and note the "bleeding."
9. Explain all the "graining" shown on a wooden desk or box.
10. Observe the gradual healing of wounds on stems.
11. See if you can trace the decayed bark round a knot.

* * *

CHAPTER XI.

Stems Performing Special Functions.

1. **Creeping Stems.**—The normal method of plant reproduction is by seeds, but sometimes we find quite massive parts of the plant separated from the parent for this purpose—the detached portion being capable of producing a new plant.

Plants frequently do this by means of runners or creeping stems. The latter may be either above or below the ground. They grow away from the parent for a relatively great distance.

Like all stems they bear a bud at their tip, and this is able

237.

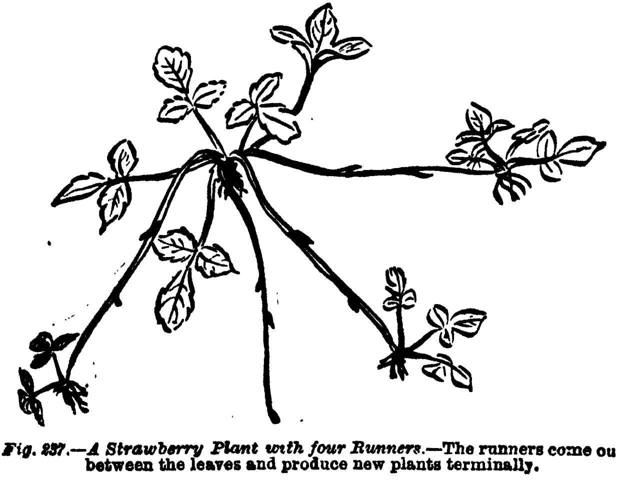


Fig. 237.—A Strawberry Plant with four Runners.—**The runners come out between the leaves and produce new plants terminally.**

to produce a new plant by means of roots growing out from its base. Such plantlets become detached from the parent by the gradual decay of the creeping stems which bore them.

2. **The Strawberry Plant.**—(Figs. 237-339.) This affords a splendid example of stems creeping along above the ground. Long running stems grow out from the angles between the leaves of the main plant. We know these are stems because they are green, they bear small leaves laterally, and they have a terminal bud of leaves. (Fig. 237.)

238.

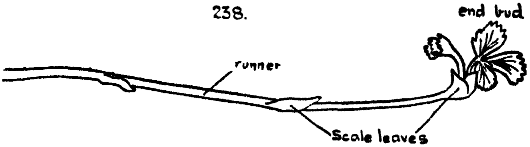


Fig. 238.—Details of a Strawberry Runner.

This terminal bud produces a group of foliage leaves (Fig. 238), small roots emerge from the base and grow down into the soil, and an independent existence begins.

239.

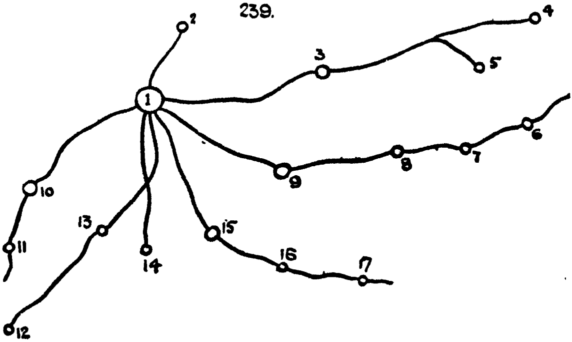


Fig. 239.—Plan of a parent Strawberry with sixteen young ones.

This plantlet may in turn become the parent of others by runners growing out between *its* leaves.

One parent strawberry plant with the large number of plantlets to which it has given rise is shown diagrammatically in Fig. 239. Strawberry affords a very evident example of a creeping stem, but we also find creeping stems below ground.

3. The Perennial Sunflower.—(Fig. 240.) What a hard task it is to free a garden plot of this plant when once it has firmly taken possession! Where we have one upright flowering stalk one year we find about a dozen the year following.

The plant thus spreads with great rapidity, and since its stems are so tall and leafy they cut off the light from other plants in their immediate neighbourhood and choke them to such an extent that they can rarely continue the struggle for more than a year or so.

240.

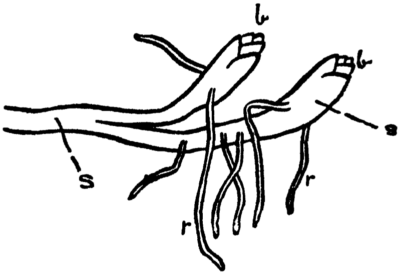


Fig. 240.—Underground stem of perennial Sunflower.—(b.) Buds; *(s.)* Stem; *(r.)* Roots.

If we dig up a small portion of the underground stems we find that thick horizontal branches are traversing the soil in all directions.

Many roots arise from these, but the most evident parts of the whole structure are the swollen tips of the branches. (Fig. 240.) The nutriment stored here is a soluble substance allied to starch in composition, and it is worthy of note that this stored food is laid up as near as possible to the stem and leaves which will require to use it for their growth in the ensuing spring. Note also the closely overlapping leaves in the terminal buds.

4. Other Fleshy Creeping Underground Stems.

(*a*) IRIS OR FLAG.—(Fig. 241.) The sheathing nature of the leaves of this plant is easily seen when we examine them in their lower aerial parts.

If we examine where these leaves are attached at the tip of the underground stem we find that the base of each leaf almost encircles the stem.

This enables us to read the series of parallel ridges which we see covering the whole surface of the stem below ground. These parallel lines are the scars of leaves which came above ground in previous years. A closer examination of any one of these scars shows that it is marked with dots at equal intervals. The decayed bases of leaves quite near to the bud frequently show whitish threads arising from these dots. We have here the remnants of the vascular bundles which passed upwards from the stem into the leaf and formed its veins.

241.

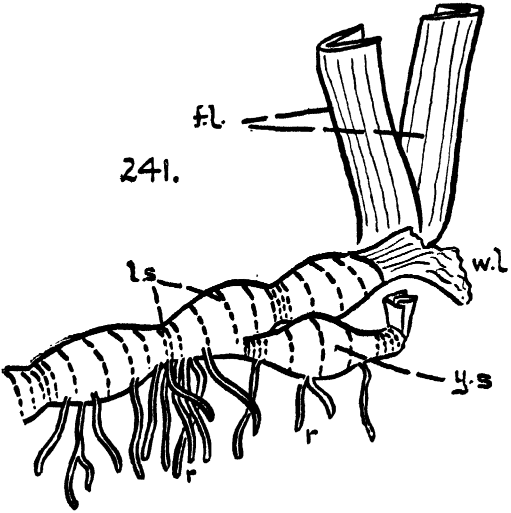


Fig. 241.—Underground Stem of Iris.—(*f.l.*) Foliage Leaves cut short; (*w.l.*) Withered Foliage Leaf; (*l.s.*) Leaf Scars; (*y.s.*) Young Stem; (*r.*) Roots.

The swollen nutritive character of this stem is very well marked, as also it is in the plant we are next about to consider.

(*b*) Solomon's Seal.—(Fig. 242.) This is another favourite garden plant. It presents a very dainty appearance with clusters of almost white bell-like flowers hanging from a slender curved leafy stem.

As in iris and perennial sunflower we have here a plant which tends to come up in larger clumps year by year, and one from which new plants can be easily transplanted by "separation." This underground stem recalls that of iris in its fleshy consistency and its series of parallel leaf scars.

The leaves differ from those of iris in that they are scale leaves, the function of which is to protect the growing stem tip. They should not be confused with the green foliage leaves, which are much larger and are borne on the aerial shoot.

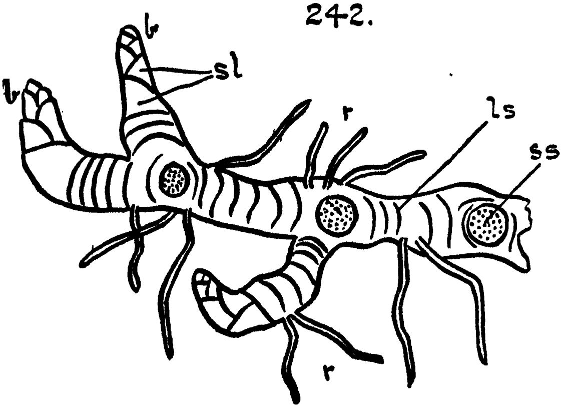


Fig. 242.—Underground Stem of Solomon's Seal.—(b.) Terminal Buds; (s.l.) Scale Leaves; (l.s.) Leaf Scar; (s.s.) Stem Scar; (r.) Roots.

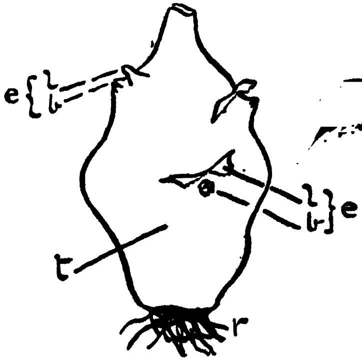
Notice where the aerial shoots or stems have died down each year, leaving a circular scar on the underground part. The student should compare these scars with Fig. 217 and discover the meaning of their dotted appearance.

5. **Tubers.**—The plants hitherto considered in this chapter have not been *greatly swollen out in special parts* of their underground stems. These we will now examine. Such swollen stems are called tubers, and their stem nature is quite obvious on a close inspection.

(*a*) **THE ARTICHOKE.**—(Figs. 243, 244.) The potato is the most familiar tuber, but its structure is much more easily understood if we examine an artichoke tuber first. We distinguish stems from roots in that the former bear leaves. The leaves on an artichoke tuber are seen to be long scale-like outgrowths, frequently possessing a basal length of over an inch. Each leaf is torn in two by the development of a bud which lies between it and the greatly swollen stem.

A reference to Fig. 170 is advantageous here, and the position of the buds should be carefully noticed.

243.



244.

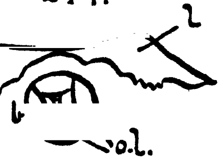


Fig. 243.—An Artichoke Tuber.—(*t.*) Tuber; (*e.*) "Eye," consisting of (*l.*) Leaf and (*b.*) Bud; (*r.*) Roots.

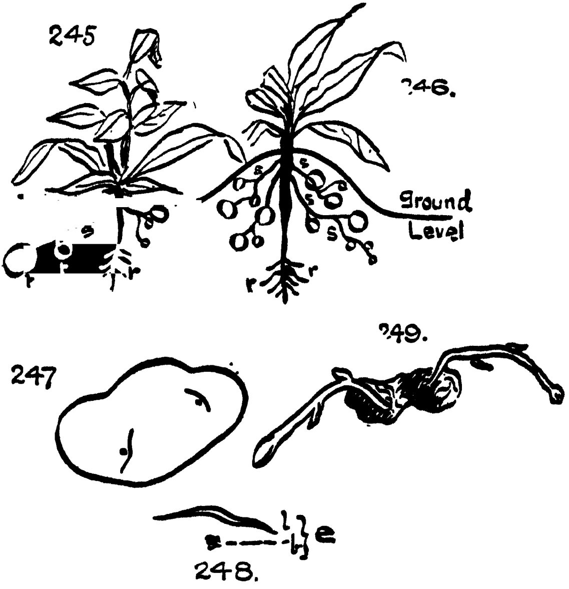
Fig. 244.—One of its "Eyes" magnified.—(*l.*) Leaf; (*b.*) Bud; (*o.l.*) Overlapping Leaves of the Bud, eight or so leaves are shown.

If we were to invert Fig. 170 we should have a precisely similar arrangement of leaves and buds, the only difference (and this an unimportant one) being the absence of leaf stalks. A leaf and bud together constitute an eye of the tuber. The name has evidently been given because of the resemblance to an eyeball and eyebrow.

The nourishment contained in an artichoke tuber enables the buds to grow out from the eyes and to penetrate the stiff clayey soil in which the plants are often so deeply planted.

(*b*) THE POTATO.—(Figs. 245-247.) The "eyes" here have exactly the same leaf-and-bud structure as in the artichoke, but the leaf generally is merely a scar and the bud is much more minute than in the latter plant. Their bud nature is manifest when they have grown out from the shrivelled tuber.

Let us examine a potato tuber to find out what particular nutritious substance the buds would abstract from it. A spot of iodine solution placed on the cut surface of a potato produces a dark blue stain. This indicates the presence of much starch in the swollen stem. The "mealy" or "floury" appearance of cooked potatoes is due to a bursting of the contained starch



POTATO (*Figs.* 245—248).

Figs. 245, 246.—*General view of two Plants*, showing the advantage of Earthing.
Fig. 247.—*Tuber with two Eyes.*
Fig. 248.—*An Eye magnified.*
Fig. 249.—*Same Tuber germinated in a dark cupboard.*
(*s.*) Stem; (*t.*) Tuber; (*r.*) Root; (*l.*) Leaf; (*b.*) Bud; (*e.*) Eye.

grains. Iodine will attack the starch much more readily in this condition. Some of these starch grains are shown in situ in Fig. 250.

Figs. 245, 246 show us why it is an advantage to heap up the earth around potato plants. We have seen in previous chapters that buds are produced in the angles between the leaves and stem. The effect of "earthing" the potato plant will be to bury more leaf bases, and consequently more buds beneath the soil.

Buds so covered tend to develop into long thin underground stems which greatly resemble roots externally, but which bear the tubers. Study Figs. 245, 246 on this point and note the absence of tubers on the roots proper.

250.

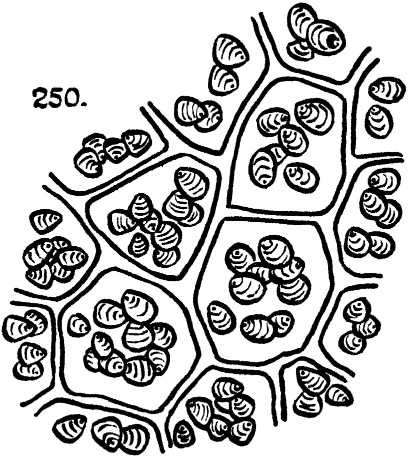


Fig. 250.—Cells from a Potato Tuber, showing starch grains *in situ*.

Another reason for earthing the plants is that the tubers would turn green if they reached the light. (N.B.—The right hand tuber in Fig. 245.)

The Celery plant is also earthed up in a very similar way. Can you give the reason?

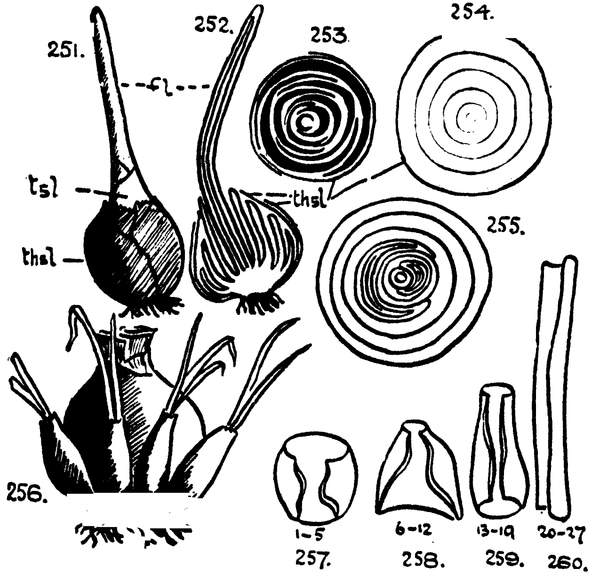
Other questions the student should seek to answer are:—

(1) Why do potato tubers separate so easily from the underground stems when they are being dug up?

(2) In what two ways can you tell which is the "tip" of a potato tuber?

6. Bulbs and Corms.

(*a*) Bulbs.—(Figs. 251-260.) A bulb consists of a short conical stem closely clothed with swollen leaves, which comprise the bulk of the structure, whilst from the base of the stem many thread-like roots arise. (Figs. 251, 252.) Outside the bulb we nearly always find membranous protective scale leaves. (Fig. 251.) In many cases these are the bases of foliage leaves which have died down.



Bulb Structure (*Figs. 251—260*).

Fig. 251.—Tulip Bulb.—(*f.l.*) Foliage Leaves; (*t.s.l.*) Thick White Scale Leaves; (*th.s.l.*) Thin Brown Scale Leaves.
Fig. 252.—Tulip Bulb in Longitudinal Section.
Fig. 253.—Narcissus Bulb in Transverse Section.
Fig. 254.—Onion Bulb in Transverse Section.
Fig. 255.—Onion Bulb in Transverse Section, showing two buds.
Fig. 256.—Narcissus Bulb, showing vegetative reproduction.
Figs. 257—260.—Dissection of a Narcissus Bulb (the numbers refer to the number of leaves found of that particular type—27 in all).

The swollen leaves may completely encircle each other, being tubular in form, as in the onion (Fig. 254), or they may only partially do so, as in the narcissus and lily. (Figs. 253, 257-259.)

If a bulb be dug up whilst in the leafy stage we can trace all stages between the long foliage leaves within and the swollen scale leaves which surround them. (Fig. 257 *et seq.*)

This suggests very strongly that the foliage leaves first act as food-making organs above the soil and later as storage reservoirs below ground.

The packing of the leaves in a bulb strongly recalls that in ordinary buds. In fact, a bulb *is* a bud, but with its leaves swollen with nourishment.

It is surprising to find the large number of leaves packed away in a single bulb. The leaves shown in Figs. 257-260 were taken from a medium-sized narcissus, and were found to number twenty-seven in all. That the leaves of a bulb contain the nourishment is well shown by boiling a few slices cut from an onion bulb and testing for grape sugar. A large amount of sugar is found, which must have been stored in the leaves, since only parts of these were boiled. On cutting an onion bulb across we frequently find a more complex arrangement of leaves than that shown in Fig. 254.

Smaller systems of circles of leaves are seen embedded in the main system. These are new bulbs (*i.e.* buds) that have arisen just where the leaves joined on to the stem, *i.e.* the normal position for bud development. (Fig. 255.)

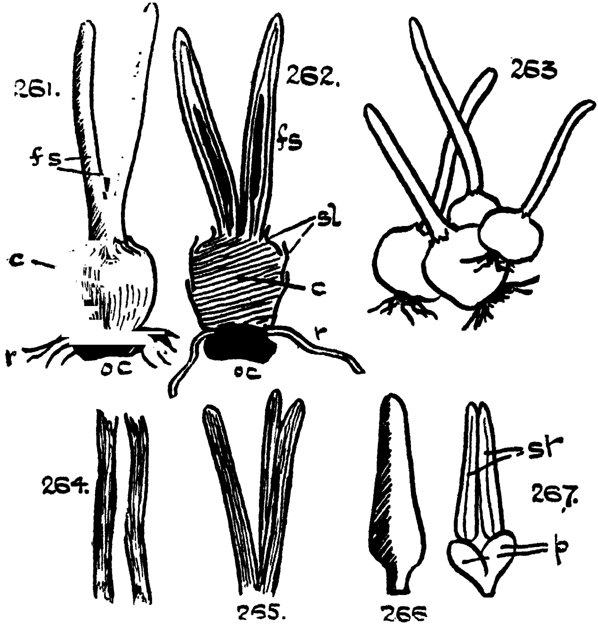
It is by such buds as these that new plants are formed, since by the decay of leaves lying outside them they come to lie externally. (Fig. 256.) Separation then easily takes place and the small bulbs commence an independent existence. Young bulbs usually produce contractile roots which pull them down in the soil to the level of their parent.

(*b*) CORMS.—(Figs. 261-267.) Corms are frequently spoken of as "Solid Bulbs." This is not a good name, because the swollen leaves of a true bulb are entirely absent. It is best to examine a crocus corm in late autumn, since then the shoots arising from it will be well developed although still below ground.

Such a corm is a brown spherical mass looking very much like a bulb at first sight. Its brown outer covering consists of chaffy scale leaves, which can easily be detached. Within these is a white mass, which is found to be quite solid when cut through. This is the stem of the plant, and therein lies the difference between a bulb and a corm, the leaves in the former, the stem in the latter, constituting the storage reservoir.

The cut surface of the stem stains very deeply with iodine solution, and the microscope corroborates the presence of starch by showing thousands of grains packed away in the cells.

At the base of the swollen stem we find a ring of emerging roots, and below these a dark shrivelled mass. The latter is all that remains of the corm of the previous year. (Figs. 261, 262.) It is a very frequent occurrence to find whole groups of small corms lying close



STRUCTURE OF A CROCUS CORM (*Figs.* 261—267).

Fig. 261.—*The Corm in side view.*
Fig. 262.—*Same in Longitudinal Section.*
Fig. 263.—*Group of Corms sprung from one parent.*
Figs. 264—267.—Contents of a flowering shoot.
Fig. 264.—*The outer Scale Leaves.*
Fig. 265.—*The Foliage Leaves.*
Fig. 266.—*The Flower Sheath.*
Fig. 267.—*The Flower.*

References.
(*f.s.*) Flowering Shoots.
(*c.*) Corm.
(*r.*) Root.
(*o.c.*) Old Corm.
(*s.l.*) Scale Leaves.
(*st.*) Stamens.
(*p.*) Petals.

together in the soil. They have evidently sprung from the same parent.

Let us examine how this has arisen. Long narrow foliage leaves spring in a group from the tip of the corm. Just within their bases tiny buds are produced, and these receive and store up in their stems the food that the leaves are making above ground. They thus develop into a group of young corms lying at the apex of a shrivelled one, which has been exhausted of its nourishment to provide for the growth of the leaves and flowers through and above the soil.

The flowers are produced in the shoots very early (*i.e.* in autumn). This accounts for the early spring flowering habit of crocus plants. The whitish shoots found on the corm in autumn contain (Figs. 264-267) :—

(1) Investing scale leaves of a white colour ;

(2) Small leaves ready to grow up above the soil;

(3) Centrally a white conical sheath which fits like a glove finger over the flower ;

(4) The flower. The petals of the latter are exceedingly small, whereas the yellow stamens and the fringed stigmas are particularly well developed.

This is the usual order of development in flowers. The essential organs are developed first, whilst the attractive organs frequently remain small almost until the opening of the flowers.

(*c*) LIFE CYCLE OF A CROCUS CORM.

(1) The corm consists of a swollen stem bearing roots below, and a crown of leaf and flower rudiments above. The whole is below ground.

(2) The leaves and flowers come above ground. Frequently the flowers do so first. The corm gradually shrivels, since it is providing these with materials for growth.

(3) Small buds are produced within the bases of one or more leaves.

(4) The food made by the leaves above ground is stored in the stems of these buds.

(5) These buds consequently develop into young corms.

(6) Each bud produces a crown of leaves at its tip.

(*d*) QUESTIONS FOR THE STUDENT.

(1) Why do we find a varying number of corms lying close together in the soil?

(2) Has the number so found any influence on the size? If so, why? and what?

(3) How is it that sometimes a corm does not flower in a particular year?

(4) Account for the early roots of young crocus corms being contractile.

(5) Account for the origin of the brown scale leaves (which have been purposely omitted from the above synopsis).

SUMMARY.

SPECIAL FORM OF STEMS.

1. **Creeping Stems:**

Aid in the reproduction of plants.
They bear leaves and buds.

STRAWBERRY: long narrow runners above ground.
PERENNIAL SUNFLOWER: slightly swollen ends. } Below ground.
IRIS: } Swollen throughout. } Below ground.
SOLOMON'S SEAL: } Swollen throughout. } Below ground.

2. **Tubers:** Special swollen spherical parts of underground stems.

ARTICHOKE: } Both bear "eyes."
POTATO: } An eye consists of a leaf and a bud.

Potatoes are earthed up to increase the number of tubers.

3. **Bulbs:** A bulb is a short stem covered with fleshy leaves. The leaves themselves contain the nourishment. New bulbs arise as buds within the old one.

4. **Corms:** A corm or "solid bulb" consists of a swollen underground stem covered with thin scale leaves, and bearing a bud of foliage leaves on one part.

5. **Character of the Nourishment stored up.**

SUGAR frequently in the leaves of bulbs.
STARCH in the potato tuber and the crocus corm.

Another soluble carbohydrate (*inulin*) in artichoke tubers and in underground stems of perennial sunflower.

PRACTICAL.

1. Count the number of plants produced from a single strawberry plant.
2. Sketch a series of Strawberry plantlets showing the development of: (1) leaves; (2) roots.
3. Ascertain the number of mature branches in an Iris underground stem without digging it up.
4. Dig up and sketch the underground stem of the Bracken or Forest Fern.

   Remove the woolly hairs from its leaf rudiments and sketch their coiled-up arrangement.
5. Take any ordinary fern and find out of what the "root" really consists.
6. Test a potato tuber for starch.
7. Weigh a potato tuber. Leave it in a dark cupboard until it has sprouted. Weigh again. Explain your results.
8. Dissect a bulb. Find how many contained leaves there are.
9. Find out whether a hyacinth bulb contains flowers at the time it is bought from the seedsman.
10. Grow bulbs, etc., in water glasses, and sketch their appearance week by week.
11. Find out how far the Colchicum corm differs from that of a Crocus.
12. Experiment with: (1) a bulb; (2) a corm, to find the extent of reproduction during three consecutive seasons.

* * *

CHAPTER XII.

The Irritability of Stems.

STEMS AS SENSITIVE ORGANS.

1. **The Effect of Light.**—Plant roots were found to be but slightly sensitive to the stimulus of light; in stems on the contrary, we have organs responding to its influence in a marked degree.

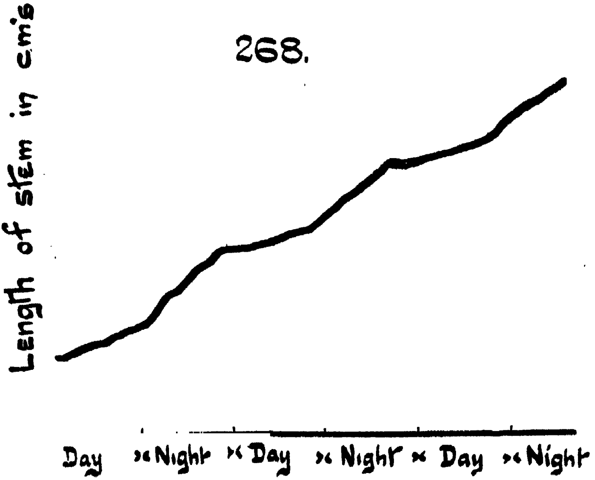


Fig. 268.—Curve to show relative growth by night and day.

(*a*) The Effect on the Rate of Growth.—If the elongating stem of any seedling be carefully measured at stated intervals for a fortnight, and the results plotted on squared paper, we uniformly find that the curve is steeper during the night times. (Fig. 268.)

Such a result shows us that the hourly rate of growth is greater when the stem is not illuminated.

(*b*) THE EFFECT ON THE TOTAL LENGTH OF STEMS.—Sunflower seeds are planted in two sets. Both sets are kept under the same conditions of moisture and temperature, in order that the rate of germination shall be uniform in so far as it is affected by these two stimuli.

One box is placed under a dark cover—a large box serves very well—the other is left exposed to light in the ordinary way.

The seedlings are left for three weeks and then those grown under cover are brought into the light for comparison with the illuminated ones.

Very pronounced differences are shown by the two sets of plantlets. (Fig. 269.)

Those grown in the light have sturdy "stems," and green seed-leaves in an expanded position. The other set of plants have produced very long "stems," but these are so slender and weak that the plants droop over the sides of the flower-pot. They are of a sickly yellow colour instead of a healthy green, and their pale seed-leaves are closely opposed to each other.

269.

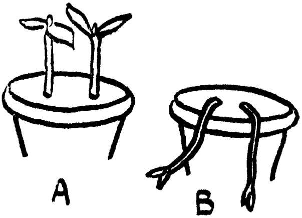


Fig. 269.—Seedlings grown (A) *in light,* (B) *in darkness.*

We learn from this experiment that darkness promotes the growth of stems in length, whilst light has a retarding action. The student can obtain the same results by allowing potato tubers to "sprout" in a cupboard and in the light.

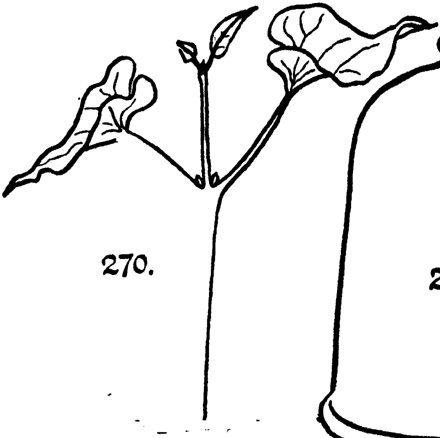
He should also examine the vegetation of shady hedgerows for further corroboration of the fact that darkness or dim light promotes the stem's growth in length.

(*c*) BIOLOGICAL SIGNIFICANCE OF THIS EFFECT—If we bear in mind the two facts :—

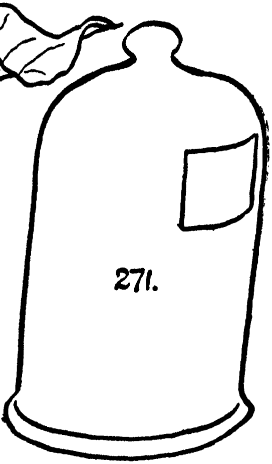
(1) That seeds germinate normally in darkness (*i.e.* underground),

(2) That they contain only a limited amount of nutritive food material,

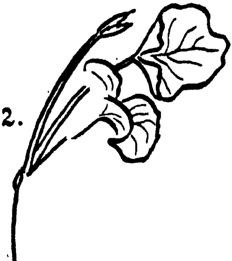
we can easily see how this rapidity of stem elongation in darkness is a distinct benefit to the plant, for by it



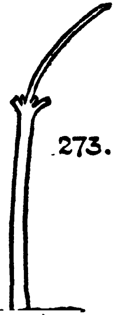
270.



271.



272.



273.

Fig. 270.—Bean Seedling grown under equal illumination.
Fig. 271.—Bell jar blackened except for the rectangular window.
Fig. 272.—Plant grown under the bell jar.
Fig. 273.—The stem tip is sensitive.

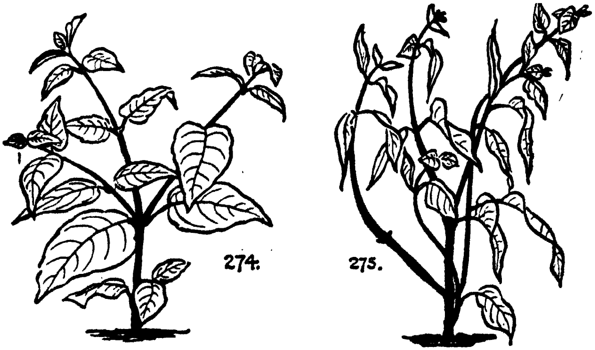
the stems can grow a greater distance through the soil and so reach the light sooner than they otherwise would.

It should be carefully remembered that plants cannot make any food for themselves until their leaves are expanded to the light. It is therefore of the utmost importance to a plant starting life that it should reach a self-supporting position before the food supplies contained in the seed give out.

(*d*) DIRECTIVE ACTION OF LIGHT ON THE STEM GROWTH. The influence of light not only shows itself on stems by causing them to rapidly increase in length, but the stems themselves are found to be bent towards the light. Light thus acts as a directive stimulus. This is very well shown by the following experiment on bean seedlings:—

One set of beans was planted in a flower-pot, and when the plants came up above ground the pot was placed before a window and turned a little each day so that the plants received an equal illumination on all sides. Fig. 270 shows the result: the stems were quite upright and the leaves were well expanded in an almost horizontal plane.

Another pot of seedlings planted at the same time was placed under a bell jar, which had been blackened all over except one small square "window." (Fig. 271.) On removing the bell jar after a fortnight or so the plantlets possessed stems curving over towards the "window," and leaves expanded in a plane almost parallel to it. (Fig. 272.)



Figs. 274, 275.—Fuchsia Plants grown under equal and lateral illuminations (*e*) WHICH CONSTITUENTS OF WHITE LIGHT HAVE A DIRECTIVE ACTION?—*We know that white light really consists of light of different colours, because it can be split up into its constituents by passing it through a glass prism; the different coloured lights being separated from one another by being bent to different degrees in their passage through the glass. A rainbow-coloured band is thus produced, having red lying at one end and violet at the other.*

If the experiment of Fig. 271 be repeated, but with a piece of reddish yellow glass placed over the window, it is found that the stems bend over towards the light very slightly indeed.

Such a reddish glass plate prevents the passage of blue light into the chamber. Evidently by this experiment we deprived the light of its chief directive constituents.

On the other hand, we should have found a very strong curvature of the stems towards the "window" if it had been covered with a blue glass instead of a red one. The bluish constituents of white light exercise, therefore, the greatest directive influence on the growth of stems.

(*f*) INFLUENCE OF LIGHT ON CREEPING STEMS.—We have found that upright stems tend to place themselves so that they lie parallel to the light's direction. We cannot find any trace of this in the runner of a strawberry plant. It lies flat upon the ground, apparently unaffected by the light stimulus. The light *does* exert a directive influence here, but it is of another kind—it causes the stem to lie in a direction at right angles to that of the rays of light. We cannot explain how t is that such opposite effects are produced by the light on stems. All we know is, that they actually do occur; we know nothing as to the mechanism or details of the process.

Will the different directive actions of light on creeping stems aid them in obtaining an adequate illumination for their leaves?

2. The Effect of Gravity.

(*a*) ON MAIN STEMS.—In germinating bean seeds the first root always proceeds directly downwards, even though it has to turn through 180° to do so. This has been proved to be due to gravity's stimulus. The first stem always grows upwards against gravity. This cannot be due to the attractive action of light, for light is absent in the soil where the first stages of stem growth occur.

If beans, from which buds have emerged, are rotated on a vertically revolving disc they grow out from it in a straight line, but in an opposite direction to the roots.

This proves that gravity exerts a directive influence on the first stem, and that this influence is a repellent one. It seems as though the stem tips "strive" to get as far as possible from the centre of the earth. Here, again, we are entirely in ignorance as to details of the mode of action of the stimulus which evokes this response, but the biological significance of this response is perfectly obvious.

(*b*) ON LATERAL AND CREEPING STEMS.—The influence of gravity on side and creeping stems may be left out of the question.

The influence, if any, is very slight indeed, for we find lateral branches growing vertically upwards, or in oblique upward or downward directions, just as the great directive stimulus (light) has dictated. Again, stems creeping along the ground show no tendency either to rise into the air or to burrow into the ground under the repellent or attractive stimulus of gravity.

3. **Influence of Contact.**—In climbing plants, the response given by stems to this stimulus is a very important one indeed. We all know that a tendril seems to "seek" a support and twine itself round it. It is this behaviour which we must now examine in some detail.

(*a*) THE NUTATION OF STEM TIPS.—When we think of an erect stem growing into the air, we have the conception that its end bud grows directly onwards in a straight

The region of special growth gradually travels round the stem, consequently the tip of the stem describes a circle.

Fig. 279 is a plan or transverse section of the growing region to show how growth at *a* tips over the end of the stem to *a′*, growth at *b* to *b′*, at *c* to *c′*, etc.; so that by the time the region *a* again becomes a specially active growing zone, the tip has described a complete circle.

All the preceding part of this section has had reference to stems growing freely in the air, without any external contact. We will now apply these principles to a climbing stem.

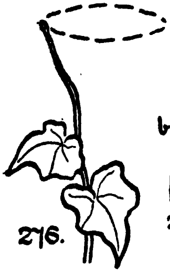
(*b*) THE PRONOUNCED NUTATION OF TWINING STEM TIPS.—Twining plant stems have very long growing tips, and the region of active growth referred to above, lies at a greater distance from the extreme tip than in other plants.

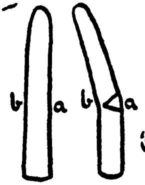
The direct result of this is, that the stem tip describes a much larger circle than it otherwise would have done.

A very successful experiment to show the considerable, yet rapid, nutation of the tips of a twining plant is that shown in Figs. 280-282.

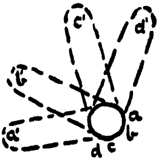
A circle of about eight inches diameter, and with some twenty equidistant radii, was drawn on a piece of cardboard. (Fig. 280.) This was slit so that it could be fitted horizontally, as in Fig. 282, with the stem of a runner bean plant growing through the centre of the circle.

The observer looked directly down on the tip of the plant, and drew its plan on the cardboard beneath.

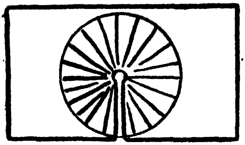

276.

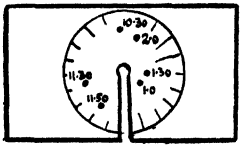


277. 278

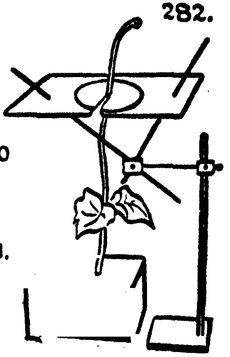


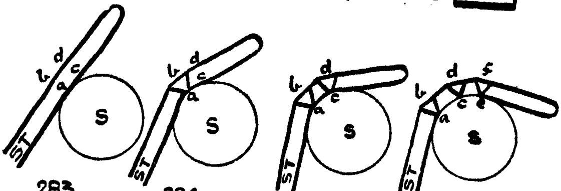
279


280



281.


282.



283. 284. 285. 286.

Fig. 276.—Showing the horizontal circle described by the tip of a twining stem.

Figs. 277, 278.—How the tip of such a stem is bent over (*towards* b) *by more rapid growth in the region* (a).

Fig. 279.—Plan showing how the circle is described by the tip.—Special growth at (*a b c d*) causing the tip to lie at (*a' b' c' d'*) respectively.

Fig. 280.—Cardboard prepared for use in experiment shown in Fig. 282.

Fig. 281.—Result of experiment. The dots mark the plans of the tip at the times stated against them. The tip thus described a complete circle in 3½ hours.

Figs. 283—286.—Four stages in the clasping of a support (s.) *by a twining stem* (st.) (For explanation see text.)

This was done at intervals during 3½ hours. The results shown in Fig. 281 are surprising. The tip of the plant described a complete circle in the time mentioned. We see from this how a twining stem may "seek" and come into contact with a support. The student is strongly advised to perform this experiment for himself with a young hop or bind-weed plant.

(*c*) HOW A TWINING STEM CLASPS ITS SUPPORT.—This must not be confused with the nutation of untouched stem tips, for although the curling round the support is brought about by a similar process of unequal growth, it is the direct response to a contact stimulus.

Let us examine the process more closely.

It happens that the twining stem (Fig. 283 ST.) touches the support (*s*) during its circular nutation. The contact of support with stem at (A) influences those cells (*a*) of the latter, which are directly abutting on it in such a way that they transmit a stimulus to the cells (*b*) lying on the opposite side of the stem.

As a result of the stimulus, these cells (*b*) grow more rapidly. A wedge-shaped mass of cells is thus produced at (*b*) (Fig. 284), so that fresh cells (*c*) are brought into contact with the support. These then transmit a stimulus to the cells at (*d*), so that increase in growth occurs in these (Fig. 285), and fresh cells (*e*) are brought into contact and so on.

The total effect is that the stem twines round and round the support.

The student should notice particularly that Figs. 283-286 are *plans* or views from above.

At the same time as this process is going on, the stem is growing upwards towards the light. The combined results of these circular and upward growths is the spiral growth of the plant around the support.

Notice in Fig. 1 how the bean stems have twined about each other. They have served as mutual stimuli.

It is only fair to add that the above account of the twining mechanism is but one of several theories which have been adduced to account for the phenomenon.

(*d*) STEM TENDRILS.—We should not call a twining bean stem a tendril, because it bears leaves : the latter name is reserved for long thread-like climbing organs which are sensitive to contact. Frequently, however, whole stems are changed into these exceedingly sensitive organs.

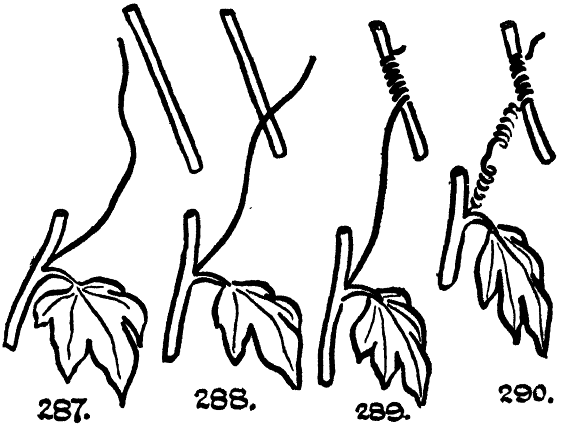
In passion flower and bryony we find these long thread-like tendrils growing out from the angles between the leaves and stem; hence we are certain that they are stems.

The behaviour of a tendril is one of the most interesting things to investigate. We note at the commencement that a plant often takes a "mean" advantage over its more sturdy neighbours by possessing tendrils, for by their aid it is able to raise its stem, and consequently its leaves to a height and an illumination only attained by its fellows after the expenditure of much food material in the construction of a rigid stem.

Very good examples of this are seen in the way bryony, hop and other climbers make their way from the ground to the top of a hedge. The following is a synopsis of the work a tendril has to perform:—

(1) It has to find a support.
(2) It has to grasp this support.
(3) It has to drag the plant upwards.
(4) It has to be firm enough to withstand being dislodged.
(5) It has to be elastic and have no tendency to snap.

(e) BEHAVIOUR OF A TENDRIL.—The tendril finds the



THE BEHAVIOUR OF A TENDRIL (*Figs. 287—290*).

Fig. 287.—The Tendril "finding" the support by nutation.
Fig. 288.—The support found.
Fig. 289.—The support clasped.
Fig. 290.—The Plant drawn up slightly.

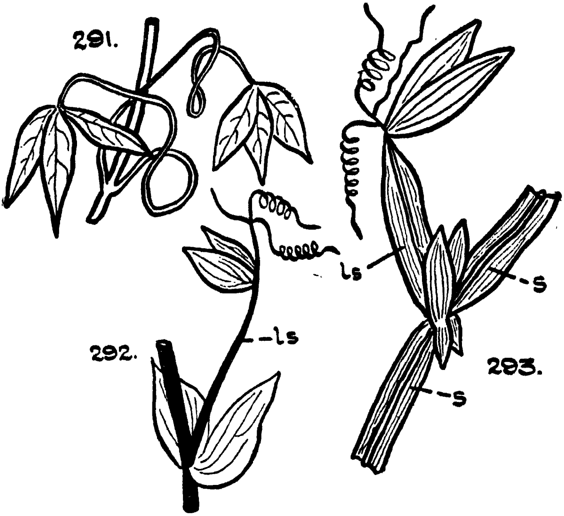
Much has been written at various times explaining *this reversed spiral as a beautiful contrivance for preventing the strain of twisting from breaking the tendril.*

In all probability it is no such special contrivance. Both ends of the tendrils are fixed, one to the support, the other to the climbing plant, and when one part of the tendril is coiled, the other must necessarily coil in the opposite direction. The reader should prove the truth of this by fastening a piece of wire at both ends and then coiling it to imitate a tendril's action. So far we have traced the tendril to a thread-like structure closely investing a support spirally, and also coiled in its remaining portion. This latter part is green and soft; it consequently acquires the necessary strength by becoming woody and elastic. It is then a perfect organ of attachment, having drawn the plant up a little and attached it firmly to the support, whilst its free region now possesses an elasticity like a watch spring and is able to open out its coils a little when the wind tends to blow the plant down.

(*f*) LEAF TENDRILS.—In many plants, parts of the leaves or even entire leaves are modified into tendrils. All that has been said above on the behaviour of tendrils applies to these also.

In the clematis (Fig. 291) the leaf stalks are the sensitive regions. In the garden pea and sweet pea (Figs. 292, 293) small leaflets are changed into tendrils.

Here both plants gain and lose by this leaf modification: they gain because they have acquired climbing organs, they lose because their food-making area is lessened.



TENDRILS (*Figs. 291—293*).

Fig. 291.—Leaf Stalk Tendrils of Clematis.
Fig. 292.—Leaflet Tendrils of the Garden Pea. N.B.—The large "**leaflets**" at the base of the leaf stalk.
Fig. 293.—Leaflet Tendrils of Sweet Pea. N.B.—The **leafy** nature of the Leaf Stalk (*l.s.*) and the Stem (*s.*).

Study the illustrations of both plants to find how they have compensated for their loss in food-making

SUMMARY.

THE STEM AS A SENSITIVE ORGAN.

1. **Light:**

(i.) Retards stem growth in length. The rapid growth in darkness aids a stem in coming up quickly through the ground.

(ii.) Causes stem tips to grow towards it. Blue constituents of the light exercise this directive action.

(iii.) *Causes creeping stems to arrange themselves at right angles to its rays.*

(iv.) *Causes leaves to become green and arrange themselves at right angles to its rays.*

2. **Gravity** *only acts on main stems. Its action is repellent.*

Nutation: *The description of a circle by a stem tip as a result of unequal growth just below.*

3. **Contact:**

Twining stems and tendrils are specially sensitive to contact. Contact causes unequal growth and a consequent clasping of the support.

TENDRILS may be either stems, leaf stalks, or leaves.

4. **Action of a Tendril:**

(i.) "Finds" and clasps the support.

(ii.) Becomes coiled in its free region and so drags the plant upwards a short distance.

(iii.) Becomes woody and elastic.

PRACTICAL.

1. Germinate different kinds of seeds in light and darkness. Measure the heights of the plants, weigh them carefully. Explain your results.
2. Plot the curve given in Fig. 268 for seedling stems of three different plants.
3. Find how long it takes sunflower seedling stems to turn towards the light.
4. Determine the exact position occupied by a detached branch with respect to the light.
5. Germinate seeds (i.) in the light, (ii.) in the dark, (iii.) supplied with blue light, (iv.) supplied with reddish yellow light. Sketch and explain your results.
6. Plant Maize, Peas and Acorns in various positions and prove that the first stem always grows upwards.
7. Perform the experiment on Nutation. (Figs. 280-282.)
8. Obtain plants with tendrils. Classify the latter into stem and leaf structures.
9. Draw a twining stem at intervals of a half-hour so that your series of drawings exhibits nutation and clasping.
10. On a calm day, stroke the concave side of a Passion Flower tendril and carefully note the results.

CHAPTER XIII.

The Structure of the Leaf.

1. **Main Functions of Leaves.**—In dealing with stems and roots the structure was understood only by reference to the work that the particular parts were performing. It is precisely the same with leaves; but since the work of leaves is so important that it requires a full treatment in a later chapter, we will content ourselves here by a mere enumeration of the work done by leaves. The following statements will be fully proved later, but they are necessary at this stage in order that the reader may appreciate the leaf's appearance, structure and behaviour.

THE GREEN LEAF:—

(*a*) Makes food when it is supplied with air, light and water;

(*b*) Gives off water vapour because it is supplied with this to excess;

(*c*) Breathes.

2. **Arrangement of Leaves on Stems.**—The guiding principle here is the necessity of light to enable each leaf to construct food. If all the leaves were crowded together on the stem at the same level, each would interfere with the other's illumination and so lessen the amount of food made. The vast majority of plant stems bear only one leaf at a level. If two leaves are borne at the same level they are on opposite sides of the stem and so do not interfere in the slightest degree with each other. If many leaves are borne at a level they are of such a shape that there is little or no overcrowding. (Fig. 294.) The common straggling "cleavers" plant found growing in hedgerows is a good example of this, so also is the oak, whose leaves are borne practically at the same level. (Fig. 295.)

In the large number of plants where merely one leaf is produced at the same level, we never find that this leaf lies immediately over the next leaf below. In fact the plant produces its leaves in such a way that it is almost impossible for them to shade the underlying leaves to any great extent. This is brought about in two ways:—

(*a*) There is nearly always a considerable length of stem between one leaf and the next.

(*b*) The leaf bases will be found to lie on a spiral line which travels round and up the stem. (Fig. 296.)

Thus there are several leaves produced before another leaf is formed exactly over one below. The student should examine actual specimens.

This latter principle will be found to apply also in cases where the leaves are borne in pairs. Dead nettle and sycamore show the phenomenon splendidly. (Figs. 297 and 299.) One pair of leaves is always placed at right angles to the pair of leaves lying above and below it. The leaves lie thus in four vertical rows, but there is little danger of overlapping because of the length of stem which lies between any two leaves lying vertically over each other. In plants like cleavers, where many leaves are borne exactly at the same level, we find that they are small and also are a good distance from the next set of leaves. (Fig. 294.)

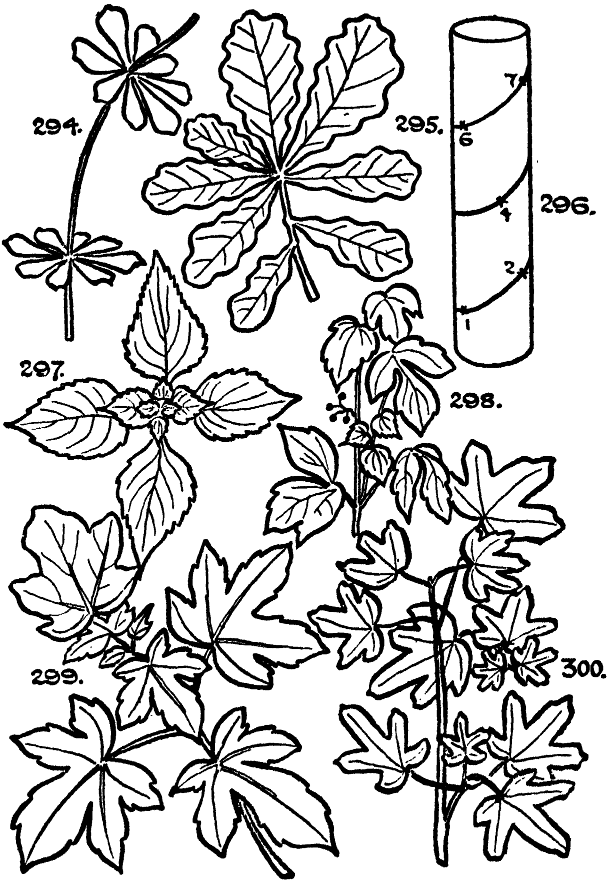
In oak, where the leaves are much larger, they do not overlap any underlying leaves, because the leaves are only produced at the tips of the branches. As a matter of fact the leaves only occupy the surface of the hemisphere shown diagrammatically in our work on the stem and its branches (page 80).

Although the positions of leaves on stems are naturally those where a minimum of over-shading is produced, the stems frequently twist during their growth in order to bring any particular leaf into a better illuminated position.

3. The External Appearance of a Typical Leaf.

(*a*) The Stalk.—A normal leaf is supplied with a stalk which holds it well out to the light. This stalk frequently remains quite short if the leaf surface is well illuminated; if, however, there be much shade the stalk elongates sufficiently to bring the leaf to more light. The leaf stalk also possesses the power of twisting during its growth in order to further the same object. (Fig. 300.)

The rigidity of the stalk serves to enable it to hold out the weight of leaf. Mathematical students should



Leaf Mosaics (*Figs. 294—300*).

Fig. 294.—Cleavers. } Note how the shape of the leaf aids in the
Fig. 295.—Oak. } formation of the Mosaic.
Fig. 296.—Arrangement of Leaves in a spiral line up the Stem, the Leaves 3 and 5 are on the other side of the Stem.
Fig. 297.—Dead Nettle as seen from above.
Fig. 298.—Virginian Creeper.
Fig. 299.—Sycamore.
Fig. 300.—Maple.

notice here the effect of the moment, or bending power of the mass of the leaf upon the leaf stalk. The development of woody tissues will tend to resist this bending and increase the rigidity of leaf stalk. The great amount of wood in the stalk is also closely bound up with the conducting function of the latter. It has to convey raw food materials from stem to leaf. It also carries manufactured food in the opposite direction. Many leaf stalks have a channelled or concave upper surface. This is of use in allowing rain water, which would otherwise bend down the leaf from its proper position, to escape easily from the leaf surface.

(*b*) THE THIN LEAF TISSUE.—Without light the leaf cannot perform its chief work. The more light falling on the leaf, *ceteris paribus*, the greater amount of food will it make. The plant has a certain amount of material to expend in producing leaves and the problem for it to "solve" is how to expend this material so as to derive the greatest benefit therefrom. Clearly the only way is to form organs of the thinnest texture compatible with the necessary strength to withstand rupture by the wind. The plant does this.

(*c*) THE VEINS.—But how flabby and collapsed this thin plate of tissue would be, unless it were held out by the system of veins, which ramifies so intimately through every part of the structure! It would be like an umbrella without the framework of ribs. The best way to appreciate the thoroughness of this support is to examine a skeletonised leaf. One of these can be picked up in Spring, especially by river sides, or may be prepared by soaking the leaf and then softly brushing it. Nothing remains but the veins, and these ramify in every direction so that you can scarcely put a pin through the "skeleton" without touching one of them. This network of veins performs two functions :—

(i.) It first forms a network sufficiently strong to hold out the softer thin tissue, yet sufficiently flexible and elastic to bend before the wind and then return to its original shape.

(ii.) Secondly, it conveys raw materials *to* the thin leaf tissue and elaborated food *from* it.

(*d*) FURTHER CONTRIVANCES HELPING TO PRESENT THE LEAVES TO THE LIGHT.—The leaf blades themselves have the power of twisting towards the light. This can be seen very well in the yew and other coniferous trees.

Many biologists think that the various shapes of leaves are for the purpose of enabling them to fit into one another, so as to form what is called a "mosaic." Certainly the "mosaics" formed by ivy leaves when the plants are lying low on the ground would seem to suggest that the angular shape of the leaf helps it to fit in between its neighbours. The shapes of the horse chestnut leaflets clearly fit them for this. One cannot, however, explain all leaf shapes in this way, for most probably the shape of the leaf is largely determined by the size and shape of the bud, the number of leaves packed away in it, and the methods of their folding.

A very good point for the student to work out is the relation that exists between the channelled surface of the leaf stalk and the degree to which the leaf tip is pointed. Do these occur in an equally pronounced degree on the same leaf? If so, why? If not, why not?

Also, is there any relation existing between the texture and thickness of a leaf on the one hand, and the appearances of its leaf stalk and leaf tip on the other? Do the veins project on both sides of a leaf?

With a little observation and thought the student will be able to account for what he sees.

(c) LEAF MOSAICS.—Figs. 294-300 give a good idea as to how leaves are arranged to utilise all the light that falls on those areas. The reader can find many other examples for himself during any half-hour spent in country or in garden. Our illustrations afford excellent examples of leaf mosaics and show how the leaves utilise the sunlight to the fullest extent. The most instructive way of treating any "mosaic" is to make a list of all the contrivances by which the leaves have been placed in position. The more or less complete shade under a tree shows us how well the plant in general has performed this vitally important work.

One word of caution is necessary in conclusion. One must not expect to find leaves fitting perfectly into one another, with not a single leaf in a shaded position. The examples given in the illustrations to this section are absolutely true to nature, but they were purposely chosen as being *very* good examples. Remember that a leaf is able to utilise the comparatively dim light which has filtered through the leaves from above. If it were not so we should not find grass and small plants growing under the shade of trees.

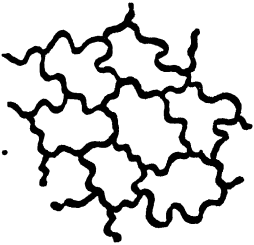
4. ***The Internal Structure of Leaves.**—This section deals exclusively with the leaf's structure as seen by the aid of the microscope.*

(*a*) THE SURFACE SKINS OF THE LEAF.—*Both upper and lower surfaces of a leaf are covered with a delicate skin of cells.* These surface skins can be very easily peeled off from thick leaves which have been allowed to soak in water for some time, and are found on examination to be thin white translucent films. Microscopic examination of these skins shows that they consist of a "pavement" of cells closely fitted together to form a continuous sheet. In long narrow leaves such as those of iris the cells are rather long and quadrangular in shape (Fig. 303), but in broader leaves the cells appear very irregular in shape, their wavy outlines fitting closely to one another just like the familiar puzzle bricks of our childhood's days. (Figs. 301-304.)

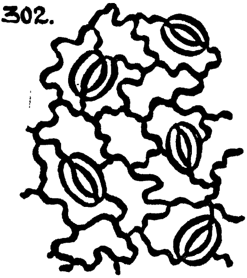
The lower skin presents an additional feature: pairs of small cells very unlike the others in appearance are thickly dotted over the whole of the view. These pairs of cells are the stomates or stomata of the plant. Each stomate (or stoma) has a small pore between its two cells, and by the greater or less curvature of these guard cells the pore is opened or closed. (Figs. 305, 306.) The stomata are very sensitive to the stimulus of light. In the light the two guard cells become greatly swollen with sap and bulge apart from each other, thus leaving a small hole between them. In waning light or complete darkness they lose much of their sap, becoming flabby and lying close to each other so that the hole is obliterated. Each hole leads into one of the air chambers of the leaf, and since there are from 4,000 to 90,000 of these stomata *on each square inch* of a leaf's lower surface we see how a very free passage is afforded to gases either entering or leaving the leaf. To get a complete conception of the structure of the epidermis or surface skins of a leaf, it is necessary to view them as they are seen in a transverse section of a leaf. (Fig. 307.) Here they form two perfectly regular bounding layers of cells of rather shallow depth. Thus an epidermal cell seen in wavy outline in Fig. 301 has an actual shape similar to that given in Fig. 304. This transverse section also shows the absence of stomata in the upper epidermis. We discern them in the lower skin quite distinctly and can see how they have the external air on their outer side and the internal air spaces of the leaf lying within.

Nearly all leaves show that the outermost wall of the epidermis is thicker than the side or inner walls. Really, this outermost wall is corky in composition, and forms a delicate but efficient waterproof skin over the whole leaf surface. When rain falls on a leaf we know that it

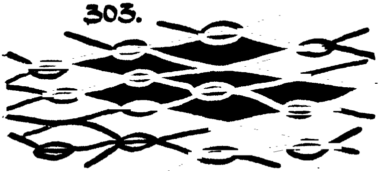
301.



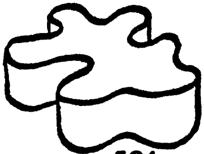
302.



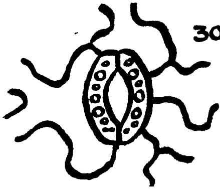
303.



304.



305.



306.

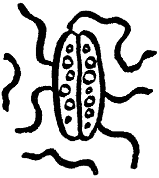


Fig. 301.—Upper Epidermis of a Holly Leaf.
Fig. 302.—Lower Epidermis of the same.—(Note the open Stomata)
Fig. 303.—Epidermis of Iris with very regular epidermal cells.
Fig. 304.—One epidermal cell from a Holly Leaf.
Fig. 305.—An open Stoma.
Fig. 306.—A closed Stoma.

does not soak through into the leaf tissues, but runs quickly off viâ the channelled leaf stalk or the pointed "drip" tip of the leaf blade. We see from the above how it is prevented from soaking through.

A very natural question will arise in the reader's mind here: "Why should not the plant utilise this rain water which has fallen on it, as well as the water it has *laboriously collected by its roots and conducted upwards through its stem?" The answer lies in the fact that such absorbed rain water would fill the leaf's air spaces and* interfere with the *gaseous exchanges going on in them.* (See next chapter.) *Also it would not contain mineral* substances as does the water *absorbed by the root.*

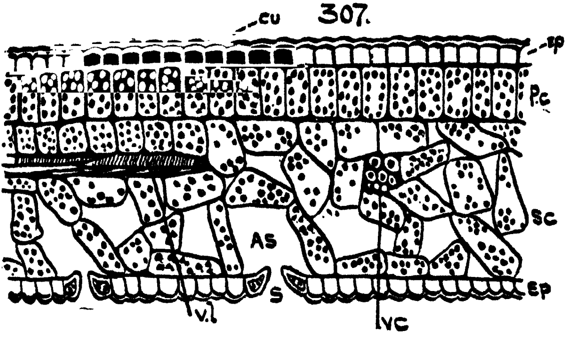
(*b*) *The Soft Green Cells of the Leaf.—These fill the space between the upper and lower epidermis. (Fig. 307.) They are arranged in two distinct ways. Those lying immediately below the upper skin are placed on end as it were and stand closely side by side like the railings in a fence.* From this resemblance they gain their name *palisade cells.* Those internal cells lying nearer the lower surface are arranged in a very loose irregular fashion. From this arrangement they are called *spongy cells.* The reason for their apparently haphazard arrangement is that there shall be as large air spaces as possible in the leaf. The student will remember that we commenced this chapter with the statement that air was necessary for food production.

A very obvious constituent of all these cells, whether palisade or spongy, is the numerous green oval or spherical bodies which are dotted about within them. These green bodies (or chloroplastids) are intrinsically the most important part of the whole plant. Without them the plant would be unable to manufacture any sugary or starchy food. Their colouring matter is due to tiny solid granules of green pigment called chlorophyll. It is most necessary to emphasise the fact that these chloroplasts are parts of the *protoplasm* or living material found in the cells. It will be greatly advantageous for the student to have a clear idea of the structure of one of these internal leaf cells, since by grasping this now much needless repetition will be saved in the two or three chapters following. (Fig. 308.) The parts shown by such a cell when cut lengthways are :—

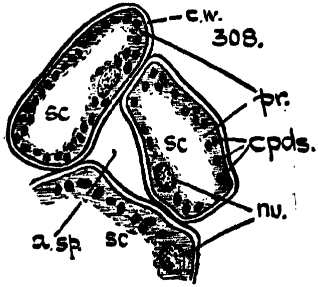
(1) A delicate colourless cell wall made of cellulose and through which water can easily diffuse. (Fig. 308 *c.w.*) This abuts at some point on an air space lying without (*a, sp*).

(2) A transparent film of protoplasm (*pr*) lying immediately within the cell wall. Certain parts of the protoplasm contain the chlorophyll and

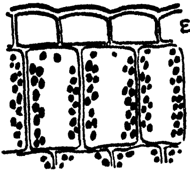
307.



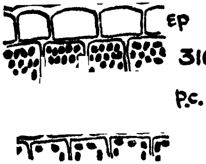
308.



309.



310.



311.

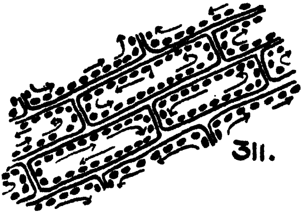


Fig. 307.—T.S. of an ordinary Leaf.—(*cu.*) Cuticle; (*ep.*) Epidermis; (*p.c.*) Palisade Cells; (*s.c.*) Spongy Cells; (*a.s.*) Air Space; (*v.l.*) Vein cut Lengthways (N.B.—The short tracheides); (*v.c.*) Vein cut Crossways; (*s.*) Stoma.

Fig. 308.—A few internal Leaf cells highly magnified.—(*c.w.*) Cell Wall; (*pr.*) Protoplasm; (*cpds.*) Chloroplastids; (*nu.*) Nucleus; (*s.c.*) Sap Cavity; (*a.sp.*) Air Space.

Fig. 309.—T.S. of a part of a Leaf in full light } to show the arrangement
Fig. 310.—T.S. of a part of a Leaf in dim light } of the Chloroplastids.

Fig. 311.—A few cells from a Leaf of Elodea, the American Water Weed, to show the movement of the Chloroplastids. (N.B.—Directions as shown by the arrows.)

constitute the chloroplastids (*cpds.*). These are embedded in the ordinary transparent protoplasm. Another important part of the protoplasm, although we are neglecting it here, is the spherical, colourless, granular nucleus (*nu.*). A nucleus is found in every living cell. Its special work is to harmonise, regulate, and co-ordinate the work done by the rest of the living material of the cell.

(3) A large central cavity (*s, c*) filled with sap. This liquid is as important to the living plant cell as the blood is to our own body. In fact it largely subserves the same functions; it contains oxygen and food for both breathing and constructive purposes, it receives the waste matters produced, and the living material requires to be completely saturated by it in order to live. With plants it also serves additional functions as will be seen in the next chapter.

(*c*) SENSITIVE NATURE OF THE LIVING MATERIAL IN THESE CELLS.—If we contrast the colours of two leaves on the same tree, we notice that a leaf standing in a strongly illuminated position is slightly paler than one in deep shade. The reason is that a strong light injures the green chlorophyll contained in the chloroplastids, and, in order to prevent this, the living material moves the chloroplastids to the sides of the palisade cells, so that they may shade one another. (Fig. 309.) In a shaded leaf they are aggregated at the end of the cells, crowded there to absorb as much light as possible, thus giving a fuller green tint to the leaf. (Fig. 310.) This example of movement of vegetable protoplasm is no isolated case. Animal and vegetable protoplasm may be considered as practically identical and exhibiting equal powers. We are familiar with the gross movements of animals. All these movements are brought about by the vitality of their protoplasm; this latter is free to move considerably, *for there are no investing walls to the cells.* In the vast majority of plants, however, each cell or speck of living material makes a protecting cell wall around itself.

Compare the rigidity of plant tissues in general, with the soft yielding nature of those in the animal world. The difference is due to the presence or absence of investing cell walls.

Since a plant has its living material boxed up, as it were, within thousands of compartments, it cannot exhibit those movements which we naturally associate with animal creatures. Nevertheless the movement can and does go on within the cell walls; for movement, like irritability, is a fundamental property of protoplasm.

The American water weed, Elodea (found attached to the mud in all our ponds), shows this movement extremely well in its filmy leaves. The protoplasm is moving round and round inside the cells and an endless procession of chloroplastids is carried along with it. (Fig. 311.)

(*d*) THE VEINS OF THE LEAF.—These present a very different appearance according as they are cut transversely or longitudinally. (Fig. 307.) When cut across we see wood vessels (with woody fibres) in the upper half, and softer bast tubes and cells in the lower half. This is not shown well in the crossways view because all the structures are roundish when so cut. In longitudinal view we see the true character of the fibres, vessels, and sieve tubes, for their lengths are then very evident.

In our previous work in connection with wood structure the wood vessels have been spoken of as if they were the sole conducting elements. Very frequently, however, and particularly in leaf veins, we find much shorter woody cells (tracheides) functioning as water conductors. (Fig. 307 *vl.*) How does it come about that the woody region is always the *upper* half of a leaf vein or vascular bundle? Does the leaf gain any structural advantage from this arrangement?

SUMMARY.

THE STRUCTURE OF LEAVES.

Leaf Mosaics.—The following are the main devices aiding their formation:—

1. The number of leaves borne at the same level.
2. The length of stem between one leaf (or set of leaves) and the next.
3. The general spiral arrangement of the leaves on the stem.
4. The twisting of the stem.
5. The presence of leaf stalks.
6. The varying lengths of the leaf stalks.

7. The twisting of the leaf stalks during their growth.
8. The relative sizes of the leaf blades.
9. Their shapes.
10. Their twisting during growth.

External Appearance of Typical Leaf.—The following points should be remembered:—

LEAF STALK.—Its woody nature—its channelled upper surface.

LEAF BLADE.—The economical expenditure of the material used in leaf formation.

Correlation throughout with the necessity of illumination.

VEINS.—Skeletonised leaves—their preparation.

The two reasons for ramifying system of veins:—

(*a*) Support and elasticity;

(*b*) Conduction to and from all parts.

Internal Structure of Leaves.

THE SURFACE SKINS:—

Upper epidermis: Flat plate-like cells only.

Under epidermis: Stomata in addition.

The stomata open in light and close in darkness.

Both skins are waterproof.

Injurious action of rain if it should enter the leaf.

Does this explain the position of the stomata on the under side only of the leaf?

THE SOFT GREEN CELLS OF THE LEAF.—The palisade and spongy cells—The chloroplastids—The air spaces. Varying positions of the chloroplastids in accordance with the degree of illumination.

Reason for plants not exhibiting external movements.

THE VEINS.—The presence and positions of wood and bast respectively.

PRACTICAL.

1. Examine and sketch mosaics. Make detailed lists of devices utilised in their formation.
2. Prepare skeletonised leaves.

Strip off the corky skin (cuticle) from any leathery leaf.

Prove that leaf veins are conducting organs. (By placing the cut end of a leafy shoot in red ink.)

Prove that the upper skin of a leaf is waterproof. (By placing equal sized drops of water on a leaf and on an oiled piece of paper and noting times taken for disappearance.)

Place a large leaf in cold water, pump air down its stalk (by means of a bicycle pump and rubber tube) and see if you can force the air out from the under side of the leaf. What does this prove?

If a microscope is available, prepare and examine all the details mentioned in the text.

CHAPTER XIV.

Assimilation.

1. Conditions for the Formation of Chlorophyll.—Sunflower seedlings grown in complete darkness are of a sickly yellow colour. If brought into the light they gradually assume the normal green tint. On microscopic examination any ordinary leaf shows the green chloroplastids contained in its juicy internal cells, but a leaf taken from the above sunflower plantlet would be found to contain yellowish plastids. These yellowish bodies are termed leukoplastids. They turn into chloroplastids only when light is present, *i.e.* they develop the green colouring matter chlorophyll.

On the other hand, chloroplastids lose their green pigment when deprived of light, and become leukoplastids. If we place a stone over some grass the latter soon becomes pale yellow; the chloroplastids have become leukoplastids. On removing the stone the grass becomes again healthy and green, its chloroplastids having been re-developed.

Why are the outer leaves of cabbage, lettuce or celery a deep green colour, yet the inner leaves are a pale yellow?

Why is the green of opening leaf buds such a delicate tint?

Why do we occasionally find one side of a potato tuber quite green?

The student will easily answer these questions, and see from the above how necessary light is both for the original formation and retention of chlorophyll.

Light is not the only condition necessary for the formation of chlorophyll.

On a bright day in early spring we can frequently notice very pale green leaves that have expanded above the ground. If these be examined on several successive days they are found to retain their paleness. Light is not lacking, for on many spring days we have almost as bright a light as in summer.

The factor retarding the development of the green colour is the lowness of the temperature. What has been said about temperature in connection with germination applies equally to all the plant functions: a low temperature means a low vitality. Until a sufficient warmth is attained it is impossible for the conversion of leukoplastids to chloroplastids to take place.

Again, if plants are deprived of all traces of iron in their mineral food they remain of a yellowish tinge. On watering such a yellow, iron-starved plant with a dilute solution of an iron salt the green colour is very soon assumed by the leaves. The main conditions on which the formation of chlorophyll depends are thus :—

(*a*) Light of a sufficient intensity.
(*b*) A sufficiently high temperature.
(*c*) Presence of iron in the absorbed mineral food materials.

2. Experiments on Starch Formation in Leaves.

Note 1.—Use clover or garden nasturtium. The most convenient way is to have these plants growing in flower-pots.

Note 2.—Double bell jars (as figured in 317) are specially useful for these experiments. They are filled with potassium dichromate solution for orange colour, and copper sulphate with ammonia for blue.

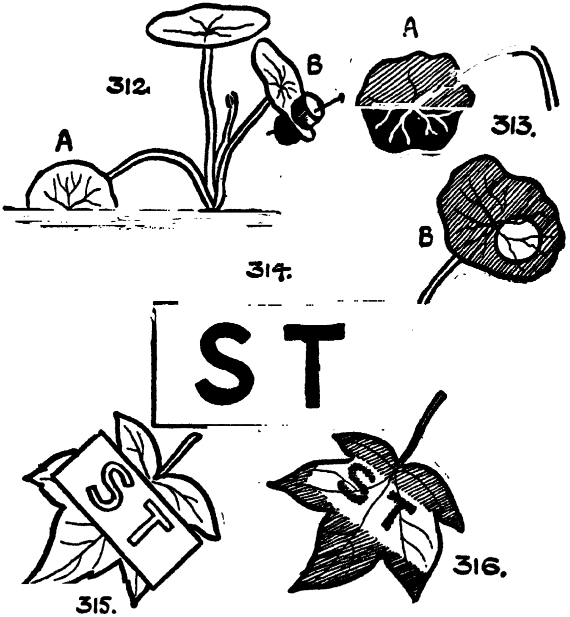
EXPERIMENT.	RESULT.	INFERENCE.
1. Place a drop of *weak* iodine solution on any common kind of starch.	A blue colour is produced.	The method of testing for starch.
2. Place a drop of *strong* iodine solution on any common kind of starch.	A dark, almost black, colour is produced.	Test for much starch.
3. How to test a leaf for starch (Sachs' method). Gather the leaf from the tree towards sunset at the end of a hot day.		
(*a*) Boil it in water.	The leaf becomes limp and flabby.	All the air in the leaf has been replaced by water.
(*b*) Soak for a time in warm alcohol (ordinary methylated spirit will serve).	The green colour comes out from the leaf, so that the latter is a pale yellow colour.	Chlorophyll is soluble in alcohol.
(*c*) Soak in iodine solution (of a sherry colour).	The leaf turns a dark colour	Starch is present.

A little explanation of Experiment 3 is necessary:—

(*a*) Enables the alcohol to penetrate the leaf tissues more quickly;

(*b*) Gives a pale colour, any deviation from which can be readily observed.

Wherever "Sachs' test" is referred to in the experiments following, Experiment 3 (*a*, *b* and *c*) on page 153 is meant.



EXPERIMENTS ON STARCH FORMATION (*Figs. 312—316*).

Fig. 312.—Garden Nasturtium with leaf (A) *partially covered by soil and with a small cork pinned on leaf* (B).

Fig. 313.—The results of testing these leaves by Sachs' method.

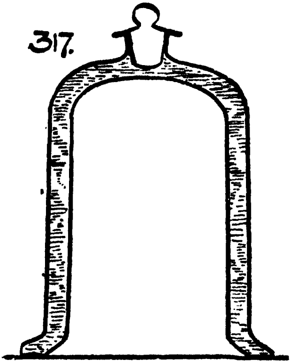
Fig. 314.—A piece of tinfoil with initials cut out.

Fig. 315.—The same pinned to a sycamore leaf while the latter is still attached to the tree.

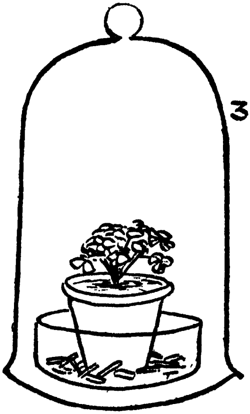
Fig 316.—Result of Sachs' test on the leaf afterwards.

EXPERIMENT.	RESULT.	INFERENCE.
4. Gather variegated leaves at end of a hot day. Sketch carefully, naming the green and yellow parts. Then test by Sachs' method.	The original yellow parts of the leaves remain yellow. The originally green parts of the leaf turn bluish-black.	Green colour (Chlorophyll) is necessary for starch production.
5. Pin a garden nasturtium leaf down to the soil so that half the leaf may be covered by the latter. Gather at end of a hot day and test by Sachs' method (Fig. 312A).	The covered half is a yellow colour; the exposed half darkens (Fig. 313A).	Light is necessary for starch production.
6. Cut a cork into two discs. Pin them on both sides of a leaf. Leave attached to parent all day. Then test by Sachs' method (Fig. 312B).	A circular undarkened region marks the cork's position (Fig. 313B).	Light is necessary for starch production.
7. Cut out your initials as a stencil on a piece of tin foil (Fig. 314). Pin this to a large leaf such as a sycamore Test for starch at the end of the day (Fig. 315).	Your initials are printed in a dark colour on a yellow ground (Fig. 316).	Light is necessary for starch production.
8. Place three plants :— (a) Under an ordinary bell jar. (b) Under an orange-coloured bell jar. (c) Under a blue-coloured bell jar. Test leaves for starch at the end of the day.	Dark colour produced. Dark colour produced. Yellow colour produced.	The red coloured light rays are used for starch production.
9. Test leaves at the end of a rather cold yet bright day.	Little dark colour produced.	Warmth is necessary for starch production.
10. Place a plant under a bell jar, but with it place a vessel containing a few sticks of caustic potash. Well illuminate for a day, and then test leaves for starch (Fig. 318).	Leaves remain a yellow colour.	No starch made. Since caustic potash absorbs Carbonic acid gas. CO_2 necessary for the plant to produce starch.
11. Smear leaves with vaseline on both sides whilst still attached to the plant. Test for starch at end of day.	Leaves remain yellow.	No starch production since air could not enter.
12. Smear *upper* sides of leaves only and test as No. 11.	Dark colour produced.	Starch has been made, therefore air entered.

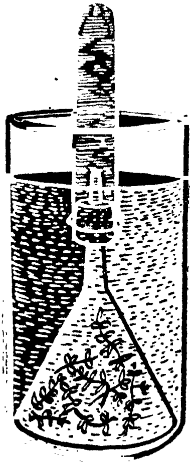
317.



318.



319.



320.

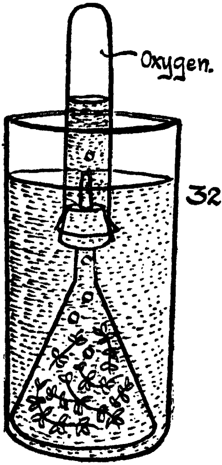


Fig. 317.—A double-walled bell jar in L.S. The space between is filled with coloured liquid.

Fig. 318.—A Plant unable to make food, because caustic potash deprives it of carbonic acid gas.

Figs. 319, 320.—Oxygen is given off during photosynthesis.

EXPERIMENT.	RESULT.	INFERENCE.
13. Smear some attached leaves on their lower side and afterwards test as before.	Leaves remain yellow.	No starch produced since air could not enter, the stomata being blocked.
14. Grow a plant in a culture solution from which potassium is lacking.	It remains in a dwarfed condition and does not increase in weight.	Potassium salts are necessary.
15. A pot plant is neglected and is not watered for a long time.	It does not form new tissue. It finally dies.	It cannot make food without water.
16. Cut one-half of a leaf from a plant at sunset and test immediately for starch.	The half-leaf darkens considerably.	Starch is present.
17. Remove the other half of the leaf early next morning and test.	The half-leaf remains yellow.	The starch has disappeared.
18. Remove the halves from many Sycamore leaves. Cut out from them a measured area of leaf surface, free from large veins (say 500 sq. cms.). Dry them thoroughly and weigh.	The weight is less than in No. 19.	
19. Gather the other halves the same evening and measure from them the same area; dry and weigh as before.	The weight is more than that of No. 18.	The increased weight is due to the starch produced.
20. Fit up any common water plant as in Fig. 319. Place in the light. (When enough gas has been collected it is tested with a glowing splint.)	Bubbles of gas rise from the plant and displace the water from the test tube (Fig. 320). The splint bursts into flame.	Probably some chemical process is going on within the plant. Oxygen has been given off from the plant.

This last experiment is one of the most important in the whole series. Water weeds use the Carbonic Acid Gas which is dissolved in the water and the rate at which the bubbles of oxygen are given off affords a ready means of estimating the rapidity at which food elaboration is proceeding within the leaves.

The student is strongly advised to perform *all* the above experiments—merely reading them through is practically of no value whatever; in addition he can show many of the facts educed above merely by the use of the apparatus of No. 20 (Fig. 319):—

To Prove:—	By Experiment:—
	Note the rate at which the bubbles of Oxygen are evolved when the plant is placed:—
(*a*) Light is necessary.	(*a*) i. In strong light. ii. In a dark cupboard.
(*b*) The effect of the intensity of the light.	(*b*) i. In bright sunshine. ii. On a table in the middle of a room. iii. As far as possible from the window of the room.
(*c*) The effects of (i.) red, (ii.) blue light.	(*c*) Under the coloured bell jars.
(*d*) Whether a plant can utilise gas light or electric light.	(*d*) In positions illuminated by these means.
(*e*) That warmth is necessary.	(*e*) i. In warm water. ii. In tap water containing pieces of ice.
(*f*) That air is necessary.	(*f*) In boiled water.
(*g*) That carbonic acid gas is not only necessary but can be utilised in increased amount.	(*g*) In water into which more and more carbonic acid gas is bubbled (Fig. 321).

3. **The Work of the Green Colouring Matter.**—The air spaces in the leaf contain small amounts of carbonic acid gas. This gas is freely soluble and becomes dissolved in the water which saturates the walls of the internal leaf cells abutting on, and forming the boundaries of, the air spaces. It diffuses through this water into that part of the sap which very intimately permeates the protoplasm, and is so brought in contact with the chloroplastids. (Carefully note that the carbonic acid gas is in solution.)

The chlorophyll of the chloroplastids arrests and absorbs the sunlight and utilises the energy so obtained in order to cause, in some subtle manner, the carbonic acid gas to combine with water to form sugar. This sugar is frequently turned by the chloroplastids into small starch grains and stored up in them for a short time. This always happens when sugar is being produced so rapidly that it cannot diffuse into the stem quickly enough.

In dealing with the food-conducting parts of plants earlier in the book, it was said that the sugary foods diffuse by slow osmotic currents through the juicy soft-walled cells. When the green cells of the leaf are making sugar, this sugar is placed in solution in the sap of the cells. From these cells it gradually oozes to others whose sap is relatively poorer in this constituent. In this way it slowly travels down the leaf stalk and into the stem.

If the green cells have much carbonic acid gas and much sunlight at their disposal, they manufacture sugar at a very rapid rate, and so their sap is speedily saturated with sugar and is unable to hold any more. It is under these circumstances that the chloroplastids change the sugar into starch and themselves act as temporary storehouses. During the night there is no activity of food elaboration; much sugar is conveyed away from the leaf cells; their sap is relatively poor in sugar; the chloroplastids convert their stored starch into sugar, which escapes into the cell-sap and thus travels gradually away from the leaves entirely. As we have seen by experiment, the starch stored in the leaves during the day disappears during the night time.

We should here note the three-fold activity of the chloroplastids :—

(1) They can make sugar from carbonic acid gas and water.
(2) They can convert sugar into starch and store it in themselves.
(3) They can reconvert this starch into sugar.

No. 1 they are able to perform by absorbing the sunlight and using its energy, whilst they produce special ferments to enable them to perform Nos. 2 and 3.

4. **Chemical Nature of this Work.**—We do not know all the details of this sugar and starch formation. The main points really known are these :—

(*a*) That carbonic acid gas and water are used.
(*b*) That sunlight, warmth, etc., are necessary.
(*c*) That intermediate organic substances are first produced, and sugar is afterwards formed from these.
(*d*) That starch appears later.
(*e*) That oxygen is evolved during the process of food manufacture.

We are in the dark in respect to details of the process. A hypothesis which best fits in with the observed facts is the following :—

1. (*a*) Water (H_2O) is split up into H_2 and O.
   (*b*) Carbonic acid gas is split up into CO and O.
2. (*a*) The H_2 and the CO are combined to form a substance of the aldehyde group CH_2O.
   (*b*) The two freed parts of oxygen join together and escape from the plant.
3. Apparently aldehyde is utilized in the synthesis of sugar.
4. If necessary, the chloroplastids may convert the sugar $C_6H_{12}O_6$ into starch $C_6H_{10}O_5$ by abstracting H_2O from it in some way (most probably by fermentative means).

The above is purely a hypothesis. The student must not accept it as a proved fact.

For us, however, these supposed details are not so important as the two main results :—

(*a*) The plant makes a complex organic food (sugar) from very simple raw materials (carbonic acid gas, water) by the aid of sunlight.

(*b*) It purifies the air, since in this food-making process it abstracts carbonic acid gas and gives out oxygen.

Figs. 323 and 324 give this in a simple way, but one worth remembering.

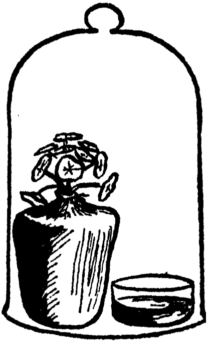
5. Names Given to this Food-Making Process.—The title of this chapter, "Assimilation," gives us the name by which the process is generally known. It is a very unsuitable name indeed. Let us see why.

An organism must first digest its food, in other words make it soluble; then it must be dissolved in some fluid (blood in animals, sap in plants); this fluid carries the food into the most intimate parts of the protoplasm. Lastly, the protoplasm *assimilates* the food (*i.e.* incorporates it with itself to be an integral part of the living material). This last-named part of the process—the actual incorporation of food with the protoplasm itself—is true assimilation. Yet the term is not used here to indicate assimilation nor absorption, nor even digestion, but merely a process which precedes all these, *viz.* the first stage in the manufacture of the food itself. Another name frequently used is "Assimilation of Carbonic Acid Gas." This is open to the same objections as the shorter name. Better terms, however, are coming into use, one of these—*Photosynthesis*—is a very good one, because in itself it indicates that a building-up process goes on by the agency of light. A further name—Photolysis—has been applied to the process. This indicates the part that light plays in the process, but emphasises the fact that a splitting up of the substances (CO_2 and H_2O) occurs.

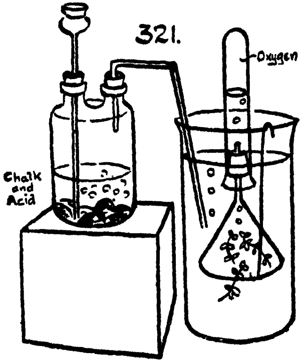
6. The Effect of Vegetation upon the Atmosphere.—In our experiments with seeds we found that they breathed rapidly; they took in oxygen and gave out carbonic acid gas, *i.e.* they fouled the air. Does an ordinary green plant breathe?

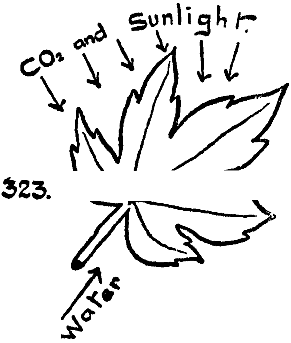
The question is easily answered by taking a plant growing in a pot, covering the pot and soil with a sheet of indiarubber or mackintosh, and placing it with a shallow vessel of lime water under a bell jar, excluding light from the whole by covering with a box. (Fig. 322.) In an hour or so the lime water is covered with a milky scum; breathing is, therefore, taking place. If we remove the box and replace the lime water with more, which is perfectly clear, leaving the whole in the sunlight for several hours, the lime water remains quite clear.

322.

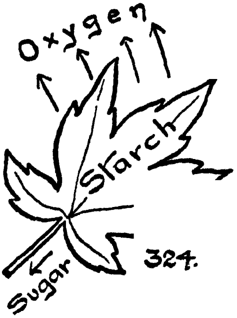


321.





323.



324.

Fig. 321.—Elodea being supplied with carbonic acid gas.
Fig. 322.—Proof that a green plant breathes.
Figs. 323, 324.—The essentials of the feeding process and its results.

These experiments show us that the plant, like an animal, is always breathing, and that it would always be fouling the air were it not that a strong feeding process goes on in the light and has the opposite effect. It would be well here to tabulate these two processes in order to appreciate their differences:—

Respiration (Breathing).	Photosynthesis (Feeding) (Or, more correctly, Food Manufacture).
1. Goes on in *all* parts of the plant.	1. Only goes on in *green* parts.
2. Is always going on.	2. Only goes on in sunlight.
3. Is a breaking down (Katabolic) process.	3. Is a constructive (Anabolic) process.
4. Protoplasm is broken down.	4. Food is made.
5. Energy is freed.	5. Energy is utilised.
6. Oxygen is absorbed.	6. Oxygen is evolved.
7. Carbonic acid gas is evolved.	7. Carbonic acid gas is absorbed.
8. Fouls the air.	8. Purifies the air.
9. The plant loses in substance and weight.	9. New organic substance is formed and an increase in weight is produced.

The above table shows how the two processes are the diametric opposites of each other.

Does a green plant purify the atmosphere or make it impure?

It depends entirely on the extent to which photosynthesis is going on.

If the plant is breathing at a greater rate than that which it is making food it fouls the air; if the two processes are going on at equal rate, the plant effects little or no fouling or purification; if the food-making process is the more rapid the net result is a purification of the atmosphere.

7. **Comparison of the Effects of Animals and Plants on the Composition of the Atmosphere.**—Animals foul the air always, since they are perpetually giving out less oxygen and more carbonic acid gas than they take in.

Germinating seeds, and also plants like mushrooms, which are not green, render the air impure in a similar way.

Green plants purify the air whenever they are making food at a greater rate than that at which they are breathing.

8. **The Nutritive Processes of Plants and Animals.**—Animals take in complex foods, they then digest them, and absorb them into their nutritive fluid (the blood). The protoplasm assimilates them to form a part of itself, and, lastly, the energy for life is obtained by the decomposition or "burning" of the protoplasm.

Green plants take in raw food materials of simple composition; they manufacture these into complex foods and then utilise them in a similar way to animals. The great difference between animals and green plants is that the latter make their foods within themselves, whereas the former take them in ready-made. In other words, animals only destroy foods, but plants construct them from simple substances before they destroy them.

The student should particularly notice how the green colour of plants preserves the balance of available energy in the world. Plants absorb the energy of the sun's rays, storing it in the form of complex foods, which either directly or indirectly constitute *our* food. We derive our vital energy by the reduction of complex foods to simpler substances. In other words, plants are constructive, animals destructive, organisms.

9. **How Starch Feeds a Plant.**—Most plants convert their sugar into starch for storage purposes. Starch is a very compact form in which the nourishment may be stored up. We have met it as a reserve material in seeds, in tubers, and in the medullary rays of the stem. Food of this kind always travels to the storage region in the soluble sugar form. On reaching the reservoir it is turned into starch grains by the activity of the leucoplastids. When required for use it is turned into sugar again by the action of diastase or some similar ferment, and in this soluble form it is able to travel through the soft cells to places where it is required.

What causes it to travel in this way?

Imagine a cell at the growing tip of a stem being actively engaged in using sugar for the formation of new cellulose walls, etc. It withdraws this sugar from its own cell sap, which is thus made poorer in sugar. Sugar, therefore, passes in by osmosis, from the sap of the next cell, and this cell repeats the process by withdrawing more sugar from the next, and so on. Thus a slow current from the storage region to the growing point is produced.

10. **Sugar or Starch Formation does not Represent the Whole Process of Food Manufacture in Plants.**—It is merely the first stage of the process. Starches and sugars contain the chemical elements—carbon, hydrogen and oxygen. But we know from our previous study of foods that proteids are also required for the synthesis of protoplasm, being incorporated into the protoplasm in this condition.

This conversion of relatively simple sugary substance into proteids involves the further combination of the nitrogen, sulphur (and frequently phosphorus) obtained from the mineral salts (nitrates, sulphates and phosphates) with the sugar already made.

This series of constructive (*i.e.* elaborative or anabolic) processes most probably goes on in the green leaf cells, although our knowledge on this point is vague as yet.

SUMMARY.

The chlorophyll of plants is only developed in the presence of light, warmth and iron.

Starch production only goes on when chlorophyll, air, carbonic acid gas, water, potassium salts, light and warmth are present.

Synonyms for sugar (or starch) manufacture :—

Assimilation.
Assimilation of carbonic acid gas.
Photosynthesis.
Photolysis.

Plants purify the atmosphere by this photosynthetic process. They use up carbonic acid gas and set oxygen free. Leaves store up starch during the day, but are quite starch-free by next morning—the starch has been converted into sugar during the night and conducted to the storage organs.

In plants Respiration and Photosynthesis are antagonistic processes.

Animals foul the air always.

Plants foul the air when their breathing is more active than their photosynthetic process.

Sugar is the form in which carbohydrate food travels through the plant.

Sugar requires to be elaborated much further in conjunction with nitrogenous compounds, before proteids are formed to repair old, or build up new protoplasm.

PRACTICAL.

Perform the experiments described in the text.

◆

CHAPTER XV.

Transpiration.

1. **A Plant gives off Water from the Under Sides of its Leaves.**—We can easily prove that a plant gives off water from its stem and leaves by taking a potted plant, enveloping the pot with a rubber sheet, tying it closely round the stem and placing the whole under a bell jar. The sides of the bell jar soon become misty and drops of water begin to accumulate on them. We can prove that the bulk of the water is given off from the leaves and not from the stem by smearing the latter with vaseline before we place the plant under the glass shade. The mistiness appears as quickly as before.

If we smear the leaves well on both sides with vaseline, the sides of the bell jar remain perfectly clear. On the other hand, the mistiness is produced if we smear only the upper surfaces of the leaves with the vaseline. Evidently we have not blocked the exits of the water. Lastly, if we smear the lower leaf surfaces and not the upper, the bell jar remains clear.

From these experiments we see that the water makes its escape from the under surfaces of the leaves, and combining this with the results of our previous microscopic examination of the upper and lower epidermis, we come to the conclusion that the stomata must be the means of egress.

Two other experiments (one gross, the other very delicate) prove the same thing.

(*a*) On a hot summer's day a sycamore leaf has a glass plate closely clamped to each of its two surfaces. It is then supported a little from below so that it still retains its normal position and attachment with the parent plant. Within twenty minutes drops of water are seen dripping from the lower glass plate, whilst the upper plate shows no signs of moisture.

(*b*) Some chemical substances have two distinct colours; one in the dry state, another in the moistened condition. Cobalt chloride is one of these. If it be thoroughly dried it is of a decided sky blue colour; on the slightest access of moisture it turns quite pink. Here we have a splendid means for identifying most delicately the presence of small amounts of water vapour. Two pieces of porous paper (filter paper or ordinary blotting paper) are soaked in a solution of cobalt chloride and allowed to dry. Even when apparently quite dry they are of a pink colour. Further drying over a bunsen flame is necessary in order to cause them to turn blue. Meanwhile, a sycamore leaf is plucked from the tree, dried between blotting paper, and is then ready for placing between the cobalt papers; but it is necessary to protect the latter from the moisture of the air. Two hot-dried mica sheets are prepared beforehand, and the experiment is arranged in this way:—Centrally the leaf, on each side of this a blue cobalt paper, outside these a dry mica sheet. The whole series is clamped closely together or merely pressed together by a small weight. Remember the leaf is living: it has only recently been plucked from the tree. Within three to five minutes sufficient water vapour has come out through the stomata on the lower leaf surface to print a pink leaf shape on the blue paper. Examination of the upper paper shows that it remains blue all over.

These experiments prove further that the stomata on the lower leaf surface are the exits of the water vapour.

2. **A Plant Possesses the Power of Sucking up Water through its Stem.**—A cut leafy shoot is fastened by a short length of rubber tubing to an open glass tube. The tube is filled with water and one end immersed in a vessel of mercury. (Fig. 325.) In a short time the mercury is found to have been drawn some distance up the glass tube. (Fig. 326.) If the plant can suck up mercury in this way, it can suck up water thirteen times more easily, for mercury is thirteen times heavier than water.

3. **Paths of the Upward Current of Water in Stems.**—The paths along which the water is transmitted can easily be seen by placing cut leafy branches in red ink or, what is better, a solution of eosin, a dye readily staining the tissues it passes through. Wherever the ink passes up the stem a red stain is found; thus, by cutting the stem across at different levels, we can determine both the paths and the rapidity of its upward passage.

The results we find corroborate our earlier work in connection with the conducting tissues; in a leafy lily or maize stem, where the vascular bundles are dotted throughout the cross section, we find very many dots or, in longitudinal sections, many narrow red lines; in a young sunflower stem we find a single ring of larger red dots in transverse section and one circular system of red tracts in the lengthwise view; in an elm branch some ten years of age we find that the wood is stained most strongly in its outermost region that is in the region of the sap wood, in longitudinal sections we find two strong bands of red, one immediately below the "bark" of each side.

Thus water travels upwards in :—

(*a*) Stems of plants possessing one seed leaf.	In very many isolated small currents.
(*b*) Green soft stems of plants possessing two seed leaves.	In a ring of isolated currents.
(*c*) Thick woody stems of plants possessing two seed leaves.	In a hollow cylinder.

When the water reaches the leaves this current (or currents) branches out into innumerable smaller currents along the veins. This is well seen by leaving the end of a branch dipping in the ink for a few hours.

4. **The Transpiration Current (or Ascending Sap.)**—There is a great tendency for students to confuse the ascending sap or transpiration current rising up through the wood of stems with the sap contained in the soft cells of the plant. This would not be so were it not for the unfortunately vague use of the word "sap." A word of explanation will make the distinction clear.

The transpiration current (or ascending sap) is a rapid stream of water with dissolved mineral substances passing upwards from roots, through the stems and branches, to the leaves *via* the dead wood cells. The main factors producing its flow are:

(*a*) root pressure (the driving force from below);

(*b*) the suction action of the leaves above.

The water of the cell sap, on the contrary, is practically stationary, except in cells near the root hairs and in the green cells of the leaf. It consists of water charged with oxygen, carbonic acid gas, foods and waste matters. It is contained in *living* cells, and has been attracted within them by osmotically active substances produced by the protoplasm. It is the "life blood" of all living vegetable cells.

5. Distinction Between the Transpiration Current and Transpiration.—The transpiration current is a rapid flow of water upwards to the leaves. One of its functions is to supply water to take the place of that which has been given off by transpiration or modified evaporation of water from the leaves.

6. Transpiration is Modified Evaporation.—Figs. 307, 308 are essentially repeated here (Figs. 327, 328), since this will save much cross reference.

The student will doubtless have noticed that the statement has never been made that plants evaporate water from their leaves. A few lines above, we have referred to this loss of water (*i.e.* transpiration) as a "modified" evaporation. It is necessary to justify the use of this adjective. In what way is transpiration modified evaporation?

Some light is thrown on the question by considering the rates of loss of water (by weighing)—

(i.) from a dead leaf;
(ii.) from an exposed water surface;
(iii.) from a living leaf.

The rates at which equal areas of the above lose water are indicated by their arrangement in the above order. A dead leaf gives off more water than an exposed water surface. A living leaf retards the evaporation, so that is the slowest of the three processes.

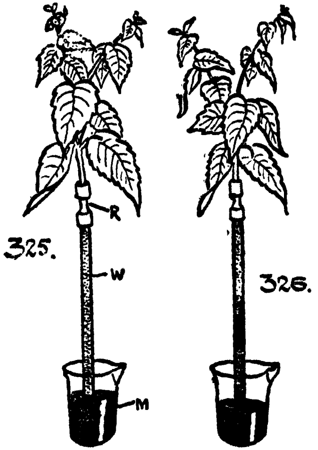
Why should a dead leaf give off water at a more rapid rate than the actual surface of the liquid freely exposed to the air?

A glance at Fig. 327 makes clear what a large area of moistened cell wall is exposed to the air of the leaf's internal air chambers. This is quite sufficient to explain the more rapid rate of evaporation.

By what means does the living leaf modify the evaporation? Structurally, the two leaves are identical—the same arrangement of stomata air spaces and exposed cell surfaces.

We note, however, one difference. In the living leaf there is a delicate lining of protoplasm lying within the cell wall; the water must pass through this in its passage from the cell sap to the air of the chamber. (Fig. 328.) It is this lining film of living material which has the power to regulate the amount of water escaping from the cells, and so from the entire leaf. Of course physical conditions (*see infra*) largely decide the amount of transpiration going on, but the protoplasm has the "last word," as it were, by regulating the flow of water passing through it. Our use of the word "modified" is, therefore, fully justified.

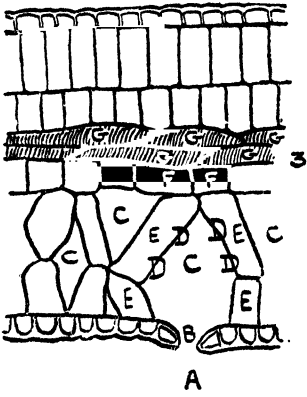
It will be a very useful revision at this point to read through that part of the root's behaviour where the protoplasm of the soft cells lying next to the wood retains its sap until it is greatly distended, and then suddenly allows the escape of the water into the wood. (Fig. 158.) Here, again, the regulating



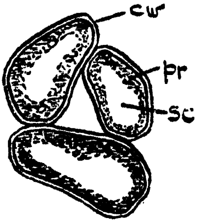
325.

326.

Figs. 325, 326.—Shewing that a leafy stem has the power of sucking up water and mercury.
Fig. 327.—T.S. leaf.
Fig. 328.—A few spongy cells from a leaf.
N.B.—The Chloroplastids have been omitted in *Figs. 327 328.*



327.



328.

action of the protoplasm is evident: it may forcibly prevent, or it may freely allow the passage of water through it.

7. Details of the Transpiration Process in the Leaf.—(Refer throughout to Fig. 327.) If the stoma *B* be open there is free communication between the atmosphere *A* and the air within the leaf air spaces *C*. We also know from previous considerations of gaseous diffusion, that if there be more water vapour in one region of the air it will pass in a diffusion current to another part, and so the composition of the air will tend to become uniform in all parts.

In applying this principle, let us suppose that the air *A* outside the plant is not saturated with water vapour. The air in the spaces *C* within the leaf is saturated with water vapour, because all the walls of the air spaces are formed by the moist cellulose walls *DD* of the internal leaf cells *EF*. Water vapour, will, therefore, diffuse through the stoma *B* into the atmosphere *A* outside the plant. The air in the spaces *C* will not then be saturated; a little water consequently evaporates from the moistened walls *D*, and so the air again is saturated with moisture. More thus escapes through the stoma. This continuous action dries the cellulose walls *D*, so that they withdraw water from the sap cavity through the intervening protoplasmic film and again become quite moist. (Fig. 328 so.) We see from this how the sap in the centre of the cells *E* gradually becomes diminished and the cells become flaccid. At least they would become so were it not that the sap is replenished by water passing by osmosis from the sap of the cells *F*, which are more turgid.

These cells *F* are always turgid, for as fast as any sap is withdrawn from them by the outlying cells *E* they withdraw water from the woody tracheid cells *G* of the vascular bundle which lies close at their side. But in a single leaf there are hundreds of cells in the *F* position and all taking a little water from the veinlet *G*. When we think of the thousands of leaves on a tree we can form some conception of the suction force these hundreds of thousands of cells exert on the wood and how they are continuously depriving it of water when transpiration is actively going on.

8. Measurement of the Amount of Water Absorbed and Evolved by a Shoot.—Fig. 330 shows us how to measure the amounts of water taken in and given out by a leafy shoot.

The shoot is tightly corked into the mouth of a graduated glass jar containing water. This is covered by a glass shade, and along with it is a shallow vessel containing calcium chloride, which substance absorbs water very readily.

If the levels of the water and the weights of the calcium chloride be obtained before and after the experiment, we are able to compare the weights of the water taken in and given off. (Every c.c. of water = 1 gramme weight.)

If the experiment be allowed to go on for several hours in bright sunlight we find that the shoot gives off slightly less water than the amount it takes up.

The reason for this is that some of the water has been used in food manufacture (photosynthesis). This experiment also proves that the leaves only require a very small fraction of the water with which they are supplied.

9. **The Potometer** (Drink Measurer) (Fig. 329).—This instrument consists of—

(1) Ч-shaped glass tube of about half an inch diameter (*A*).

(2) A long glass tube of very narrow bore bent at right angles a short distance from each end (*F*).

(3) A ruler or scale, preferably in centimetres (*E*).

(4) A small vessel of water (*G*).

In preparing the instrument for use (Fig. 331) a strong jet of water is run in *C* from the tap until it escapes both from the *H* and *B*. The cut end of the shoot *M* has already been forced through a rubber bung *N*, and this is then tightly inserted into *B*. We are thus sure that the water is in close contact with the cut shoot. The end *H* is next closed with the finger and a cork is tightly fixed into *C*. If this has been done properly no water will escape from *H* when the finger tip is removed. The end *H* is immersed in water as Fig. 332, the instrument is then ready for use. The *H* end is raised from the water (Fig. 333) and air is seen to be sucked slowly into the tube. *H* is next immersed in the water and a bubble (Figs. 329-334) slowly moves up and along the glass tube at a rate proportional to that at which the water is being sucked up by the leafy stem. Consequently we are able to measure the rate of the water absorption by noting the time taken for the bubble to pass a certain distance along the scale. When the bubble reaches the Ч tube it passes up into the straight limb and remains at *C*. Another bubble can then be imprisoned at *H* and the whole process repeated. The great value of the instrument is that we can place the leafy shoot in different positions (*i.e.* under different conditions) and so investigate the factors which influence the rate of the transpiration current in the stem.

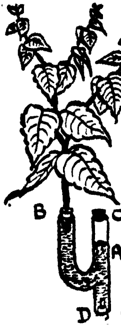
10. Experiments with the Potometer.

Experiment.	Result.	Inference.
1. The shoot is placed close to the glass of a sunlit window.	The bubble travels rapidly.	
2. It is moved back to a table in the centre of the room.	It travels more slowly.	Light promotes transpiration. Darkness retards transpiration.
3. It is placed in a dim corner of the room.	It travels more slowly still.	
4. It is covered over with a large wooden box.	It gradually ceases to move.	
5. It is placed under a bell jar in the sunlight.	The bubble goes more slowly. Later bubbles hardly move at all.	The greater the humidity of the air, the less rapidly does transpiration go on.
6. The bell jar is removed.	The bubbles travel more quickly.	
7. It is placed under the bell jar with a calcium chloride vessel.	There is a much increased rate of travel.	
8. It is placed in a part of the garden away from the wind.		Wind promotes transpiration.
9. It is placed in a windy part of the garden.	The rate is more rapid than in Experiment 8.	
10. It is tested in a shady place. (*a*) In the morning. (*b*) At noon. (*c*) In early evening. And the temperature of the surrounding air is taken at the same times.	The rate is most rapid when the temperature is nearest the optimum.	Temperature influences transpiration (as indeed all vital functions of plants).
11. Some of the leaves are cut off the shoot.	The bubble travels more slowly.	The leaves are the path of escape of water
12. The leaves are smeared with vaseline on their under surfaces.	The bubble becomes stationary.	Blocking the stomata prevents the escape of water

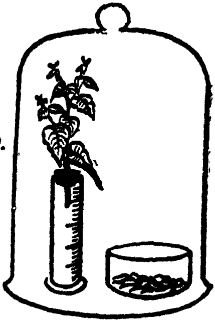
11. Conditions affecting the Rate of Transpiration. Results of the above Experiments.

(*a*) Light.—The action of light in promoting transpiration is twofold: It enables the soft internal leaf cells to make food rapidly; for this they both require more water and mineral substances and give more water off into the air spaces; it has a direct action on the guard cells of the stomata, causing them to open.

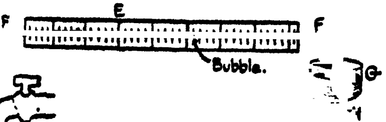
Details of Opening and Closing of the Stomata.—If the student examines Figs. 305-307 he will find that the guard cells of the stomata contain chloroplastids, but the other epidermal cells do not. A great deal depends on this.

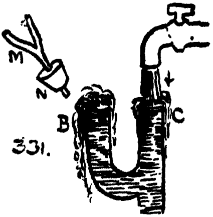


329.



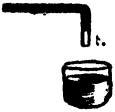
330.



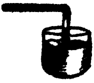


331.

332.



333.



334.

Fig. 329.—The Potometer in use.
Fig. 330.—Experiment to compare the amounts of water absorbed and evolved from a leafy shoot.
Fig. 331.—Method of fitting the upper half of the instrument.
Figs. 332—334.—Imprisoning a bubble for use.
Fig. 332.—The tube full of water.
Fig. 333.—Air drawn in.
Fig. 334.—The Bubble imprisoned.

At the beginning of the day the stomata are closed. When a moderately strong light falls on the leaf, the stomatal guard cells are among the first to receive it and they soon manufacture a small amount of sugar which becomes dissolved in their cell sap. Sugar is an osmotically active substance, and it attracts more water into the guard cells so that they become highly turgid or distended with sap.

The guard cells have their walls thickened in such a way that the cells separate from one another whenever they are in a turgid condition.

Briefly the action of light in promoting transpiration is as follows:—

(1) It enables the guard cells to make sugar.

(2) Sugar within the guard cells causes their turgescence.

(3) The turgidity causes the stomatal pore to be opened.

(4) The water vapour can now escape from the air chambers of the leaf.

The opposite series of events occurs on the approach of darkness.

(1) The guard cells cease to make sugar.

(2) The sugar already made speedily oozes through to other cells by osmosis.

(3) The amount of watery sap of the guard cells is consequently diminished.

(4) The guard cells become flabby.

(5) As a result they become closely adpressed to each other by their margins.

(6) The stomatal pore is now closed.

(7) Transpiration practically ceases.

(*b*) HUMIDITY OF THE AIR.—The references here are to Fig. 327.

The air in the leaf's spaces (*C*) is always saturated with water by evaporation from the moist cellulose walls *D*. If the air (*A*) outside the plant be very dry there will be a very rapid outward passage of water vapour through *B*. If the air (*A*) were completely saturated with moisture there would be no escape of water vapour whatever. The contrivances by which some plants utilise this principle will be found in the ecological treatment of the subject. (See chapters XX.-XXII.)

(*c*) WIND.—The air (*A*) immediately outside the leaf has more water vapour in it than air situated further away from the plant. We have previously noted how this water vapour will gradually pass by diffusion to other parts of the air. The wind, however, in blowing across the leaves removes this air (*A*) very rapidly, and air containing less water vapour is brought into this immediate region.

This is one action of the wind in promoting transpiration. Aspiration is another of its effects. When wind blows across the stomatal openings it exercises a suction action and draws out some air and water vapour from the leaves, like the passing wind draws the smoke up a chimney.

SUMMARY.

TRANSPIRATION.

Transpiration is modified evaporation of water from leaf surfaces. It is the physical process of evaporation regulated by the protoplasm according to the needs of the plant. It is also largely influenced by external physical conditions (temperature, light, wind, humidity of the air). As a consequence of transpiration the leaves are able to draw water up the stem. A large amount of water is necessary because the mineral salts required for food-making can only be absorbed by the roots in very dilute solutions. The excess of water is given off (via the stomata) from the under surfaces of the leaves. In green stems the water ascends in small isolated streams; in woody stems as a hollow cylinder. The path of this upward transpiration current is the woody parts of the plant. The comparative rate of the transpiration current under different conditions is most easily observed by use of the potometer.

PRACTICAL.

1. Perform the experiments detailed in the text.
2. In connection with potometer experiments with a woody branch, calculate, from the rate of movement of the bubble, the rate at which the transpiration current is ascending the stem.

CHAPTER XVI.

Flowers.

1. **Vegetative and Sexual Reproduction.**—In the chapter dealing with creeping and swollen stems, we found that the main purpose of these was to produce new plants. This reproduction of new individuals was called Vegetative Reproduction, and consisted essentially of the separation of a *large part* of the parent plant to form a new one. By this means well-developed plants are very soon produced, but there is the disadvantage that the plantlets grow in close proximity to the parent. In addition, it often happens that wintry climatic conditions would be fatal to a plant having large stems and leaves. How is the plant to live through such an unfavourable time? The necessity of another kind of reproduction is thus made manifest. By the *sexual* method of reproduction the plant is able to produce very tiny plants, which—

(*a*) Are very small, and so can be easily transported to a considerable distance;

(*b*) Can be covered with hard resistent coats able to withstand adverse climatic conditions ;

(*c*) Are capable of a more vigorous life and growth than that of the parent at the time that it produces them.

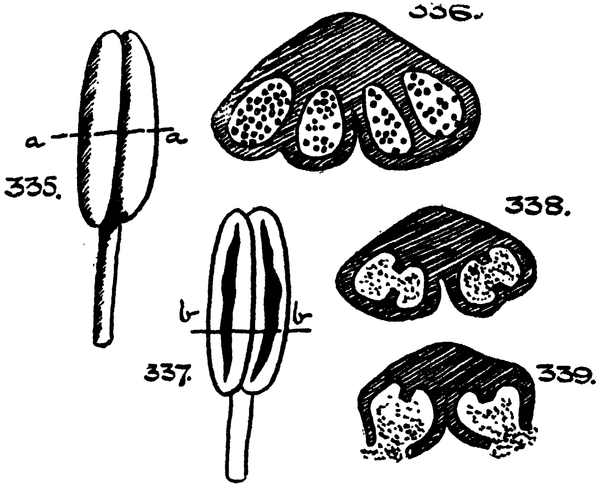
2. **What is Meant by a Sexual Process.**—The last sentence in the previous section requires some explanation. It is known that plants, feeble and nearing the end of their life, can produce seeds containing plants endowed with the full vigour of youth. This new access of vitality is the result of a sexual process. By a **Sexual Process** is meant the union of two germs of life to form one. Wherever in the entire living world, whether in animals or in plants, we find distinct sexes;

these male and female organisms have each been primarily differentiated from one other for the purpose of producing the two kinds of life germs or sexual cells, and later in the life history one of the male cells fuses with a female cell, with the result that a vigorous descendent is developed from the latter. The union of a male and female cell enables the latter to produce a vigorous offspring.

3. **The Biological Significance of Flowers.**—Leaving aside all considerations of the beautifying effects of flowers, for this is the way in which flowers appeal to most of us, we must regard them more from the plant's "point of view." A plant produces flowers for the functions of—

(1) Formation of its two kinds of sexual cells.

(2) Providing facilities for the fusion of these cells.



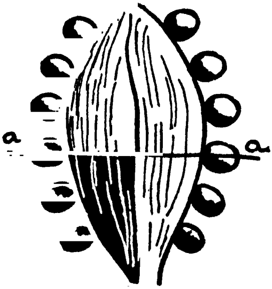
STRUCTURE OF A STAMEN (*Figs. 335—339*).

Fig. 335.—The Head and Stalk.
Fig. 336.—Transverse section along a a.—The four pollen chambers are shown.
Fig. 337.—The Stamen bursting along two lines.
Figs. 338, 339.—Two stages in transverse section.
Fig. 339.—Transverse section along the line b b.

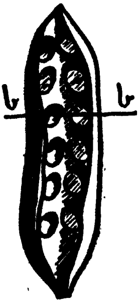
4. The Sexual Cells in Flowers.

(*a*) THE MALE CELLS.—Inside the vast majority of flowers we find yellow-stalked bodies—the stamens. These are essentially cases for the production of the male cells—the pollen. The stalk is a subsidiary structure and may or may not be present. On examining the head of a stamen, a groove is seen throughout its length. (Fig. 335.) If we examine the stamen cut across, we find that there are four chambers full of pollen grains. These chambers or pollen sacs, as they are called, run throughout the length of the head. When the pollen grains are ripe, the head usually bursts along two long lines (Fig. 337) and the powdery pollen easily escapes. Stages in the bursting of pollen sacs are shown in Figs. 338, 339. The pollen grains are the male sexual cells. The stamens are the sexual organs producing those cells.

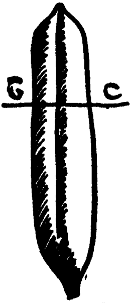
(*b*) THE FEMALE CELLS.—In the centre of the majority of familiar flowers there is a green structure of varying



340.

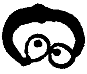


341.



342.

343.



344.

345.

INFOLDING OF A CARPEL TO FORM A CHAMBER (*Figs. 340—342*).

Fig. 340.—The expanded Carpel.
Fig. 341.—The Carpel infolding.
Fig. 342.—The Carpel infolded.
Fig. 343.—Its section along a a.
Fig. 344.—Its section along b b.
Fig. 345.—Its section along c c.

The ovules are seen as spherical bodies on the margins of the Carpel. In each ovule in *Figs. 343—345* the egg cell is marked as a dot.

form lying surrounded by the stamens. This is the ovary or pistil of the flower, and its structure is, at first, rather hard to understand, because so many varieties are found. Essentially, it is a case or chamber containing the female cells. It is made up of one or more parts called carpels, more or less resembling leaves, and often wrongly described as modified leaves. They are folded on themselves to form one or more chambers. The female (or egg) cells do not lie naked in the ovary chamber as did the pollen grains in the stamen. Each individual egg cell, or ovum, is embedded in a small spherical cellular mass called an ovule, and these ovules are attached to the walls of the ovary chamber. (Fig. 341.) Students should carefully distinguish between the ovum, the ovule and the ovary. Let us now examine a few typical ovaries.

The main structures to be borne in mind are :—

(i.) The walls of the ovary chamber consist of one or more carpels;

(ii.) Ovules are borne in the ovary and are generally attached to its wall;

(iii.) Each ovule contains one female or egg cell—the ovum. We can regard the carpel as a leaf-like body bearing the ovules on its margins. (Figs. 340, 343.) Its walls become folded to form a chamber with the ovules tucked away within. (Figs. 341 *et seq.*)

The ovules thus lie in a single line down the wall of the ovary.

Does this recall the arrangement of the parts in a pea pod? Would there be a similar structure in the pea flower?

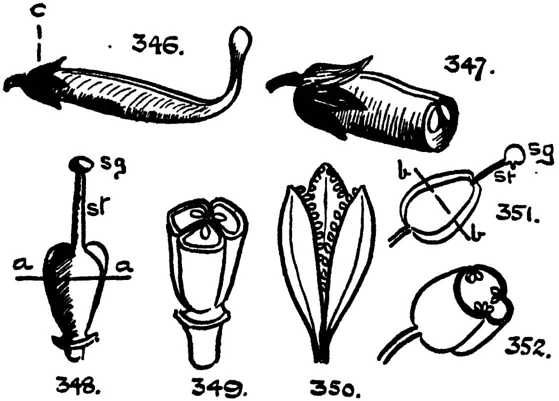
The ovary chamber in this case (Fig. 346) is formed by one carpel only, but in the greater number of flowers there is more than one carpel.

In the marsh marigold ovary (Fig. 403 and 405) we find about a dozen carpels standing upright in the centre of the flower. Every one of these contain ovules arranged down one of the sides. A more usual state of things is that the carpels are united together. A lily, for instance, has three combined carpels. (Fig. 348.)

Let us imagine three carpels, each a chamber, as in Figs. 342, 347, fused together to make one body. Naturally, an ovary such as this will present three chambers (Fig. 349), when cut across at a level, *a*——*a*. The ovules will all spring from the central region, which is composed of the six fused margins of the carpels.

A pansy ovary affords us an example of another carpel combination. (Fig. 351.)

Picture three leaf-like carpels, each as in Fig. 340, becoming combined by their edges (Fig. 350), and this gives the explanation of the ovary structure here. The ovary is one chamber and the ovules are arranged in three lines or regions down its walls. (Fig. 352.)



STRUCTURE OF OVARIES (*Figs. 346—352*).

Fig. 346.—Ovary of Sweet Pea.—(c.) Calyx.
Fig. 347.—Same cut across to show Ovules attached to the side.
Fig. 348.—Ovary of Lily.—(sg.) Stigma; *(st.)* Style.
Fig. 349.—Same cut across, three-chambered with ovules borne down the central region.
Fig. 350.—Diagrammatic view of the structure of a Pansy Ovary.—The three carpels joining by their edges.
Fig. 351.—Actual appearance of a Pansy Ovary.
Fig. 352.—Same cut across, one-chambered with the ovules in three regions on the wall of the ovary.

5. The Necessity of Pollination. Pollination and Fertilization.—The egg cells are not only completely enveloped in their respective ovules, but the latter are contained in a closed ovary chamber. How is the male cell (pollen grain) to reach the female (egg) cell?

It must first be conveyed to the tip of the ovary chamber *A*); next it must grow and pierce the wall of the chamber (*B*); then it must traverse the open space (*C*) to the ovule before it can enter the uncovered tip (*D*), lastly, it must bore into the ovule to fuse with the egg cell (*E*) within. (Figs. 353, 354.)

The transference of the pollen from the stamens to the tip of the ovary is termed pollination. The actual fusion of the tip of the pollen tube with the female egg cell is known as fertilization. The pollen grain only adheres to the ovary wall in

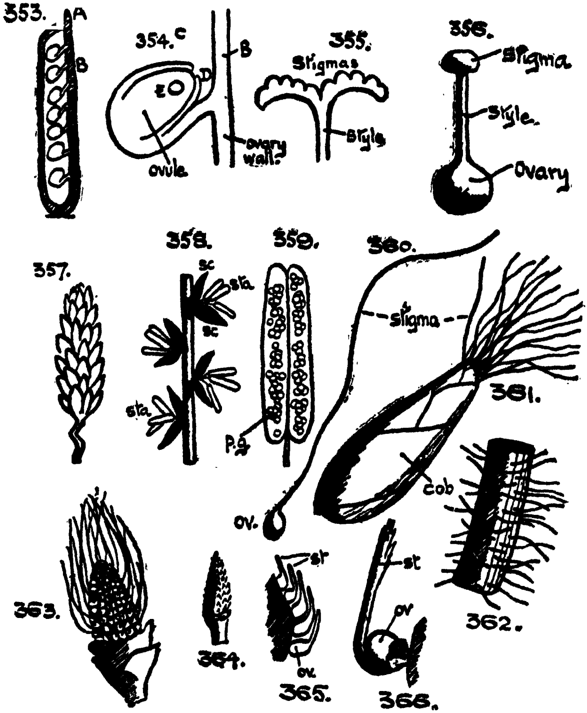


Fig. 353.—*Longitudinal section of Pea Ovary showing contained Ovules.*
Fig. 354.—*Details of a small part of above.*—For explanation of references see text.
Fig. 355.—*Enlarged view of the rough Stigmas of Willow.*
Fig. 356.—*Primrose Ovary.*

MAIZE (*Figs.* 357—366).

Fig. 357.—*Head of unopened Male Flowers.*
Fig. 358.—*A few opened Male Flowers,* each with scales and stamens.
Fig. 359.—*The Stamen enlarged.*—(*p.g.*) Pollen Grains.
Fig. 360.—*A single Female Flower.*—(*ov.*) Ovary.
Fig. 361.—*A Cob of Female Flowers with projecting Stigmas.*
Fig. 362.—*A small part of its Stigma much magnified.*
Fig. 363.—*A young Cob deprived of its leafy investment to show the conical head of Female Flowers.*
Fig. 364.—*Very young stage of Fig.* 363.
Fig. 365.—*Small part of Fig.* 364 *in longitudinal section.*
Fig. 366.—*Young Female Flower magnified.*—(*st.*) Stigma; (*ov.*) Ovary.

one particular spot. This is the *stigma*—the rough sticky tip of the ovary. The roughness of the surface here (Fig. 355) is of great use in detaining the pollen grains; the stickiness furthers the same object. It is due to the secretion of a sugary fluid, which also affords nourishment to the pollen tube, which grows out from the pollen grain.

Since in many flowers the ovary is very deeply situated, it is necessary for the stigmas to be carried up on the end of a long stalk or *style*, so that they may be placed in a convenient position to receive pollen grains. The typical ovary is thus a chamber in the centre of the flower, with a thread-like style arising from its tip and with one or more stigmatic or receptive surfaces borne at the end of the style. (Fig. 356.)

6. **Mechanism of Pollination.**—If the same flower bears both stamens and ovary, it may be so arranged that pollen falls on the stigmas and so effects self pollination.

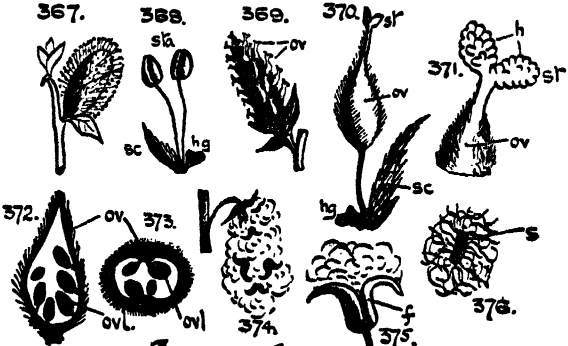
Some very simple flowers contain only stamens *or* ovaries: here cross-pollination is a necessity. By cross pollination is meant the transference of pollen from one flower to the stigma of another. Cross pollination produces seeds which grow into more healthy plants than those from seeds resulting from self pollination; therefore, it is to a plant's advantage to obtain cross pollination if possible. Plants usually are dependent upon the wind or insects to effect cross pollination. Full details as to how they promote this co-operation will be found at the end of Chapter XVII., which might be referred to here with advantage.

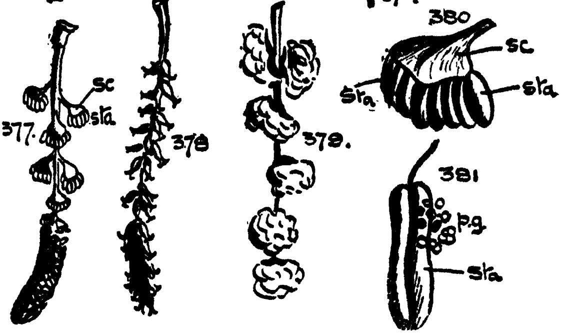
7. Flowers of Various Complexity.—(*A*) Simple Unisexual Flowers.

(*a*) MAIZE. (Figs. 357-366.)—The flowers are enclosed in scales. The male flowers each consist of three stamens. These are large, and so there is abundance of pollen to be scattered by the wind. The flowers are situated in numerous clusters towards the top of the plant; this again aids the wind's dispersal of the pollen. (Figs. 357, 359.)

The female flowers are borne in a conical mass (the cob) closely covered with many sheathing leaves. (Fig. 361.) Each flower consists of one carpel surmounted by a very long thread-like stigma. The bunch of stigmas projects from the cob as a tassel of hairs. Each stigma is hairy throughout its length so that the pollen very easily catches on them. (Figs. 361-366.) The student should note how the female flower is fitted for wind pollination.

(*b*) WILLOW. (Figs. 367-376.)—A willow catkin consists of a





WILLOW FLOWERS AND FRUIT (*Figs. 367—376*).

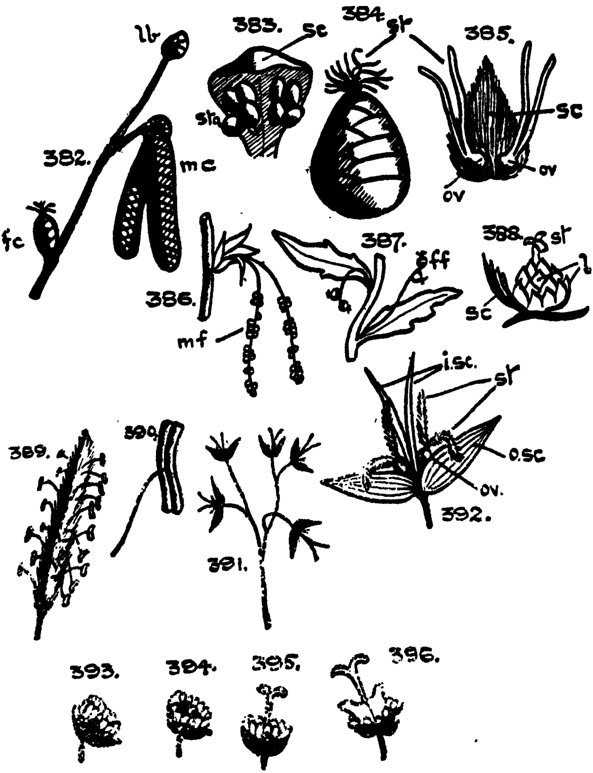
Fig. 367.—Male Catkin.
Fig. 368.—The Male Flower.
Fig. 369.—Female Catkin.
Fig. 370.—The Female Flower.
Fig. 371.—Tip of the same.

(sc.) Scale; (*sta.*) Stamens; (*h.g.*) Honey Gland; (*st.*) Stigmas; (*h.*) Hairs; (*ov.*) Ovary.

Figs. 372, 373.—Female Flower cut lengthways and crossways to show the contained ovules.
Fig. 374.—Ripe Catkin showing burst Fruits.
Fig. 375.—The Fruit. *Fig. 376.—The Hairy Seed.*

POPLAR (*Figs. 377—381*).

Fig. 377.—Male Catkin. *Fig. 378.—Female Catkin.*
Fig. 379.—Ripe Female Catkin.
Fig. 380.—One Scale from a Male Catkin, showing the hanging stamens.
Fig. 381.—The Stamen with escaping pollen grains.



HAZEL (*Figs. 382—385*).

Fig. 382.—Twig with Leaf Bud (l.b.), *Male Catkin* (m.c.) *and Female Catkin* (f.c.).
Fig. 383.—One Scale (sc.) *from the Male Catkin viewed from within.* (*sta.*) Stamens.
Fig. 384.—Female Catkin with projecting stigmas (st.).
Fig. 385.—One Scale (sc.) *from Female Catkin viewed from within.* (*ov.*) Ovaries (each is a female flower).

OAK (*Figs. 386—388*).

Fig. 386.—Hanging Catkins of Male Flower (m.f.).
Fig. 387.—Catkins, each bearing two Female Flowers (f.f.).
Fig. 388.—The Female Flower enlarged. (*sc.*) Scale; (*l.*) Leaves; (*st.*) Stigmas.

stem covered with tiny scale leaves. One catkin bears flowers of the male sex, whilst the female catkins are borne on another tree some distance away. A flower lies within each scale of the catkins. The male flower consists of two stamens with a small honey gland or nectary at their base. (Figs. 367, 368.)

The female flower consists of an ovary and a honey gland. The papillose surface of its two stigmas requires strong magnification in order to be seen. The ovules are arranged in two ranks on the ovary wall. (Figs. 369-373.) Although the above flowers are so simple we find ample provision made to ensure the visits of bees to both kinds of flowers.

(*c*) POPLAR.—(Figs. 377-381.) The female catkin resembles that of willow except that there is no honey gland. The pollen is blown to the stigmas by the wind. It should be noticed how the stamens of the male catkin hang vertically from the scale. (Fig. 380.) They are attached by very slender stalks and are easily moved by the wind.

(*d*) HAZEL.—(Figs. 382-385.) This differs from willow in that both kinds of catkins are found on the same tree; in fact, they are generally to be seen on the same branch. The male catkins are the more evident. They are long and pendulous, and are generally borne in pairs on the stem. (Fig. 382.) Within each scale there are two flowers of four stamens each. The female catkins look like buds. They can only be recognised from buds when the female flowers lying within push out their stigmas as a tiny scarlet bunch at the tip. (Fig. 384.) The female flowers are borne in pairs within each scale. Each possesses two long stigmas. (Fig. 385.)

(*e*) OAK.—(Figs. 386-388.) The male catkins of oak are long threads hanging vertically from the tips of the branches. At intervals along these threads small groups of stamens represent the male flowers. (Fig. 386.) The female flowers are harder to find. They are produced in groups

---

GRASS (*Figs. 389—392*).

Fig. 389.—Foxtail Grass in Male Flowering stage, with projecting stamens.
Fig. 390.—One Stamen enlarged.
Fig. 391.—Meadow Grass in Female Flowering stage.
Fig. 392.—Two Female Flowers enlarged. (*i.sc.*) Inner Scales; (*o.sc.*) Outer Scales; (*st.*) Stigmas; (*ov.*) Ovary.

SYCAMORE (*Figs. 393—396*).

Fig. 393.—Flower in Male stage.
Figs. 394—396.—Upgrowth of stigmas and development of the Fruit.

of two or three on a stalk projecting from the angle of young leaves near the tip of the stem. (Fig. 387.) Each female flower consist of an ovary with three stigmas. A close investment of many small leaves clothes the lower half of the ovary. (Fig. 388.)

In connection with British trees, bearing wind pollinated catkins, the student should note:—

(a) A large amount of pollen is produced;
(b) The pollen is protected from damp;
(c) The pollen is readily accessible to the wind;
(d) The stigmas project strongly from the female flowers;
(e) The time of flowering is before that of leaf expansion.

(B) Simple Bisexual Flowers.

(a) COMMON GRASSES.—(Figs. 389-392.) These figures show the flowering of grasses in (1) male, (2) female stages. When both stamens and ovary are borne in the same flower, it very frequently occurs that they are ripe at different times; thus self pollination is an impossibility.

In the ordinary grass flower we have three stamens and an ovary. There are no leaf-like parts to the flower; the scales by which it is invested are borne on the stem. In the male stage the stamens hang out on slender stalks freely exposed to the wind. They are specially constructed in order to dangle with the slightest breath of air. (See Figs. 389, 390 for the attachment of the stalks.) In the female stage, two feathery stigmas push their way out from the scales, and are thus in an admirable position to catch the wind-blown pollen. (Fig. 392.)

(b) SYCAMORE.—(Figs. 393-396.) The flowers hang down in long stalked clusters. In the bud stage each has a green investment, which is seen in the open flowers as five small leaf-like parts. Within these are about a dozen stamens, and the forked stigma grows out later from the centre of these.

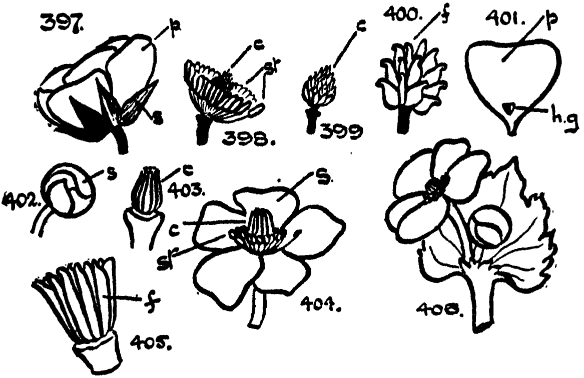
Here we have a bisexual flower protected in the young stage by leaf-like parts. This investment we call the perianth. This is the first flower we have taken where it can easily be seen; the previous flowers have either been quite naked or have had such a tiny perianth that it was negligible.

(c) MARSH MARIGOLD.—(Figs. 402-406.) This is the large golden kingcup or water-blob of our brook sides.

Examined in the bud stage it presents a similar appearance to the sycamore flower bud, but is much larger.

The open flower, however, presents a far different appearance. Its green protecting leaves have now expanded and turned a brilliant golden yellow in order that insects may be attracted. This is an interesting case of a primarily protective organ performing an attractive function later. (Figs. 402-404.)

The willow flowers gave us an example of insect attraction by honey, this flower shows insect attraction by colour.



BUTTERCUP (*Figs. 397—401*).

Fig. 397.—Side view of Flower, showing sepals (*s.*) and petals (*p.*).
Fig. 398.—Petals and Sepals removed, to show Stamens (*st.*) and Carpels (*c.*).
Fig. 399.—The Ovary made of many Carpels.
Fig. 400.—The Fruit of many "Nuts."
Fig. 401.—A Petal from within. (*h.g.*) Honey Gland.

MARSH MARIGOLD (*Figs. 402—405*).

Fig. 402.—Bud enveloped by Sepals.
Fig. 403.—The Ovary of about twelve Carpels.
Fig. 404.—Open Flower, showing sepals, stamens and carpels.
Fig. 405.—The pod-like Fruits.
Fig. 406.—Flower and Bud. Note the two functions of the calyx.

(*d*) BUTTERCUPS.—(Figs. 397-401.) Here is a further degree of complexity. The bud has green protecting leaves as in sycamore and marsh marigold, but when the flower opens, another circle of leaf-like organs grows out. These (the petals) are of a bright yellow, and if one be separated from the flower and examined, a small honey gland of greenish yellow colour is found near the base of the inner side. (Fig. 401.)

The perianth or leaf-like part of the flower thus presents two distinct regions:—

(1) The outer green protective part (the calyx);

(2) The inner yellow attractive part (the corolla), within these we find many stamens and, centrally, very many small carpels. (Figs. 397-399.)

We will now synopsise the four regions found in this and in thousands of more complex flowers.

(1) *The Perianth*:	
Calyx (of green sepals) ...	... Protective
Corolla (of coloured petals)	... Attractive.
(2) *The Stamens*	... Pollen producing.
(3) *The Ovary* of carpels ...	... Seed producing.

SUMMARY.

Reproduction.

(i.) VEGETATIVE.—By separation of large portions of the parent gives the offspring a good start in life.

(ii.) SEXUAL.—By formation of a seed produces a compact plant which can be transported some distance.

Sexual Process.—The union of two sexual cells.

It results in the formation of a *vigorous* young organism.

Flowers are organs producing the sexual cells.

Sexual Cells in Flowers.

(i.) MALE.—Pollen grains—enclosed in stamens at first.

(ii.) FEMALE.—Egg cells—enclosed in ovules—these in carpels

Ovary.—A chamber formed by the folded carpel or combined carpels.

Parts of the Ovary.

(*a*) The chamber—containing the ovules.

(*b*) The style—presenting the stigma.

(*c*) The stigma—receiving the pollen grains.

Pollination.—Transference of pollen to stigma.

Fertilization.—Fusion of male and female cells in the ovule.

Two Kinds of Pollination.—Self and cross.

Cross pollination is advantageous since healthier offspring produced.

Simple Flowers.

(i.) May be of one sex only, *e.g.* willow, oak and other catkin-bearing trees, perianth frequently absent.

(ii.) Both sexes may be present in a naked flower, *e.g.* grasses.

(iii.) Both sexes present within a green perianth, *e.g.* sycamore.

(iv.) Both sexes present within a coloured perianth, *e.g.* kingcup.

(v.) Both sexes present within a perianth of two kinds (calyx and corolla), *e.g.* buttercup.

The Four Organs Present in most Flowers.

(i.) Sepals (calyx) for protection.
(ii.) Petals (corolla) for attraction.
(iii.) Stamens for pollen production.
(iv.) Carpels (ovary or pistil) for seed production.

PRACTICAL.

1. Examine as many simple flowers as possible. Name the parts.
2. Give detailed drawings of a lily stamen.
3. Construct paper models of different kinds of ovaries.
4. Open a flower bud, carefully cut away the stamens, cover the bud with a paper bag, and note results.
5. Deal similarly with another flower, but remove the ovary instead of the stamens.
6. Cover a young shepherd's purse plant with a bell jar (or tie a paper bag over its young flowering stalk).
   Does it produce seeds? Does the plant use cross or self pollination?
7. Treat a flower pot of clover in a similar way. Are the results the same as in experiment 6?
   What do you infer from your results?
8. Carry out experiments to ascertain whether cross pollination is a necessity to the following plants:—Mignonette, sunflower, bean, wallflower, laburnum, garden geranium, willow, lupin, gorse, sycamore, buttercup.
9. Germinate pollen grains in weak sugar solutions and examine their pollen tubes under the microscope.

* * *

CHAPTER XVII.

Flowers of Greater Complexity and their Mechanisms.

In Chapter XVI. a few typically simple flowers were described with a view to illustrating:—

(*a*) Naked flowers of one sex;

(*b*) Bisexual flowers with distinct calyx and corolla.

Our present object is to discuss in some detail with reference to more highly organised examples, the intimate relation which exists between flowers and insects. Since many flowers cater for the visits of particular intelligent insects possessing long tongues, and have a structure expressly adapting them to these insects, it will be well at the outset to briefly consider the lengths of insects' tongues.

The following table is condensed from Willis' "Flowering Plants and Ferns."

1. Lengths of Insects' Tongues:—

CLASS.	KIND OF INSECT.	LENGTH OF TONGUE.
(A) Short-tongued Group.	**(1) Short-tongued flies (such as dung flies and small bluebottles).**	**Less than 4 mm. in length.**
	(2) Beetles (especially the small bronze-black beetle).	**Always less than 6 mm. (sometimes only half this length).**
	(3) Small bees, butterflies and moths.	**Less than 6 mm.**

Class.	Kind of Insect.	Length of Tongue.
(B) Long-tongued Group.	(1) Long-tongued flies (particularly the "hover flies").	From 4 to 12 mm.
	(2) Larger bees (Hive and Humble bees).	Always longer than 6 mm.
	(3) Larger butterflies and moths.	"
	(4) The hawk moths.	80 mm.
	Some other moths even have tongues of	300 mm. length.

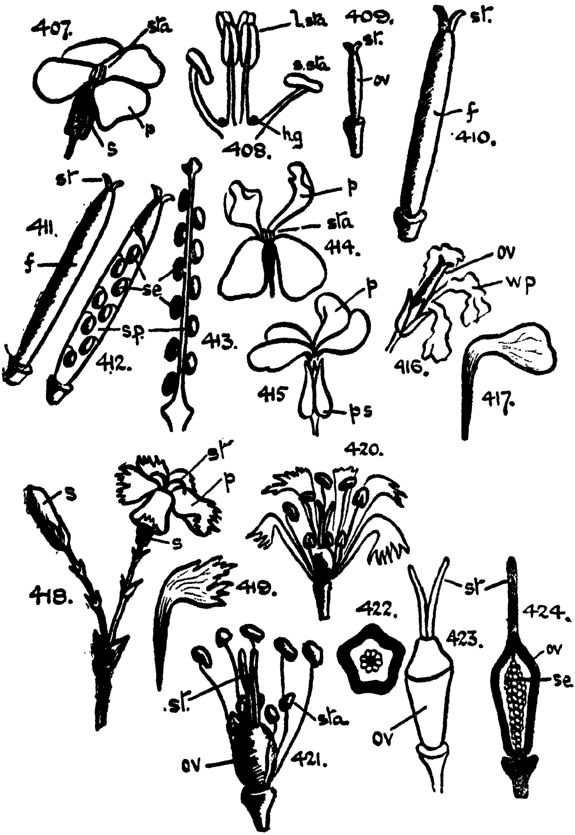
One of the most interesting structures that complex flowers show is a tube whose length serves to keep short-tongued insects away from the nectar, whilst the longer-tongued insects are easily able to reach it. Our first few examples will exemplify how flowers form such a tube in a variety of ways.

2. **Wallflower or Stock.**—(Figs. 407-417.) In these flowers the four green sepals stand upright, thus making a tube which effectually conceals the honey, the glands of which are developed deep down in the flower at the base of two short stamens.

The heads of the stamens (six in all) lie just at the mouth of the tube in an ideal position for dusting with pollen the head and upper thoracic region of a bee whilst groping for the honey which lies deep down in the flower. The bee does not enter the flower, it merely protrudes its tongue (or proboscis) into the tube. The stigmas lie close at the mouth of the tube also, and after pollination and fertilization have occurred, the ovary grows up into the young fruit which is shown developing in Fig. 416.

3. **Garden Pink.**—(Figs. 418-424.) Here another contrivance is seen. The calyx, seen as a close investment round the flower bud in Fig. 418, remains as a tube holding all the inner parts of the flower in position. On cutting away the tube of combined sepals all the parts fall outward, as in Fig. 420. There are five fringed petals, ten stamens and a central ovary made of two carpels, as indicated by the presence of the two stigmas. Inside the ovary, a central mass of ovules covers a rod running through the middle of the chamber. (Figs. 422-424.)

As in the wallflower, the honey is produced at the bases of the stamens; also here we have three attractions:—honey, colour, and scent. The figures also show that the stamens have



WALLFLOWER (*Figs. 407—410*).

Fig. 407.—Complete Flower. *Fig. 408.—The Stamens.*
Fig. 409.—The Ovary. *Fig. 410.—The Fruit.*
(s.) Sepal; (p.) Petal; (*l.sta.*) Long Stamen; (*s.sta.*) Short Stamen; (*h.g.*) Honey Gland; (*st.*) Stigma; (*ov.*) Ovary; (*f.*) Fruit.

STOCK (*Figs. 411—417*).

Fig. 411.—The Fruit complete.
Fig. 412.—The same with part of the Ovary-wall removed. (*s.p.*) Skinny Partition; (*se.*) Seeds.
Fig. 413.—Fruit with both sidewalls removed, showing seeds attached to both sides of the membrane.

their pollen ready before the stigmas have expanded to receive it. A later stage of the flower with expanded stigmas is given in Fig. 418.

4. **The Hollyhock.**—(Figs. 425, 426.) The hollyhock offers colour and nectar attraction, but it forms its tube by combining all the stalks of its stamens. Here again the pollen is ripe before the stigmas are receptive. The latter grow up into a brush-like mass after the stamens have withered. (Fig. 426.)

5. **Sweet Pea.**—(Figs. 427-433.) This is another flower which combines its stamens into a honey-concealing tube. Its mechanism is so interesting that it merits a few lines of explanation.

The five petals differ much from one another in size and shape. One large petal (the standard) gives a conspicuousness to the whole flower by standing erect at the back. Two smaller petals (the wings) afford convenient landing places for the bee that grasps them both in alighting. It must be remembered that the bee is a comparatively heavy insect, and the weight of his body is sufficient to depress these two side petals. The wings have projections on their inner sides, which fit into corresponding depressions in the two lowermost petals (the keel), so that when the wings are depressed by the bee, so also is the keel. The keel is very aptly named, for it exactly resembles the keel of a boat. Its contents can be well seen in Fig. 430.

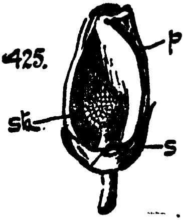
There are nine stamens combined into a tube and one stamen left free above. (Figs. 430, 431.) Two small holes are left at the junction of this stamen with the others, and an insect is only able to reach the honey by inserting his tongue through these holes. The stigma of the flower is found projecting from the midst of the stamens. It has grown up from the ovary which lies within the stamen tube. It should be particularly noted from Figs. 429 and 430 that the stamens and stigma lie just within the tip of the keel.

Fig. 414.—Complete Flower.
Fig. 415.—Same from the side, to show pouched sepals (*p.s.*).
Fig. 416.—Withering Flower with developing Fruit.
Fig. 417.—A single Petal detached from the Flower.

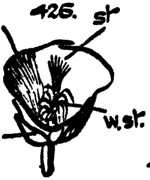
GARDEN PINK (*Figs. 418—424*).

Fig. 418.—Flower and Flower Bud. *Fig. 419.—A single Petal.*
Fig. 420.—Open Flower with Sepals removed.
Fig. 421.—Same after Petals have been removed.
Fig. 422—The Ovary in cross section.
Fig. 423.—General view of the Ovary.
Fig. 424.—The Ovary in longitudinal section. Note the ovules clothing a rod running centrally through the Ovary.

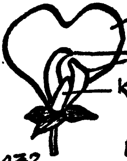
425.



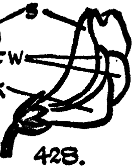
426.



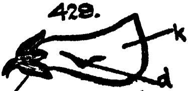
427.



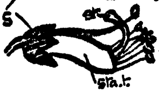
428.



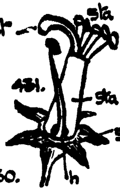
429.



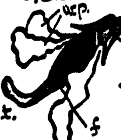
430.



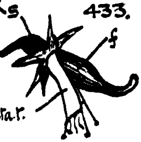
431.



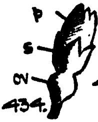
432.



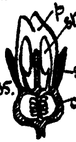
433.



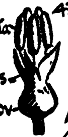
434.



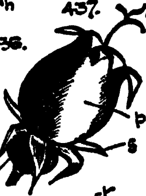
435.



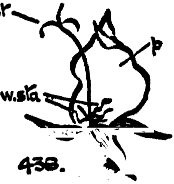
436.



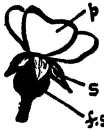
437.



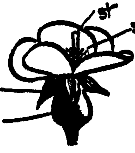
438.



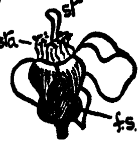
439.



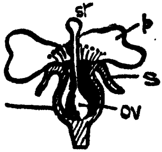
440.



441.



442.



HOLLYHOCK (*Figs. 425, 426.*)

Fig. 425.—Bud Stage of Flower cut open. The stamens are seen as a massive head. Their stalks are combined into a tube.

Fig. 426.—Older Flower, treated similarly to show the withered stamens (*w.st.*) and the projecting stigmas (*st.*) beyond them.

SWEET PEA (*Figs. 427—433*).

Fig. 427.—Front view of Flower. *Fig. 428.—Side view.*

(*s.*) Standard; (*w.*) Wings; (*k.*) Keel.

Fig. 429.—The Keel seen sideways. N.B.—The depression (*d.*) into which the wing fits.

Fig. 430.—The Keel removed to show Stamen Tube (*sta. t.*), with the stigma projecting beyond the stamens. N.B.—The free upper stamen.

Fig. 431.—The same viewed from above. Note the hole (*h.*) at the base of the free stamen—the only path to the honey lying within the base of the stamen tube.

Figs. 432, 433.—Two withering Flowers, with developing pods or fruits (*f.*); (*w.p.*) Withered Petals.

We are now in a position to investigate the mechanism of the flower.

The bee alights on the wings and presses them down by the weight of his body. This, in turn, causes the depression of the keel by the interlocking connection of the parts. The stigma is thus uncovered and rubs against the lower surface of the bee's abdomen. With further depression the stamens emerge and deposit pollen upon his abdominal region.

Certain growers of sweet peas report that self-pollination often occurs in the flowers, notwithstanding their complex mechanism for cross-pollination.

The student is strongly advised to investigate the flower mechanism of Gorse, Lupin, Broom and Broad Bean. The best way to do this is first to watch the insects visiting the flowers, then afterwards to examine the floral structures.

6. **Canterbury Bell.**—(Figs. 434-438). This flower forms a tube by combining its petals into the familiar purple or white bell. A strange fact about bees is that they are especially attracted by, or "have a weakness for," blue and kindred colours. Any bluish or purple "bell" flower may be set down almost at once as a "bee flower." The size of the Canterbury bell fits it for bees. The student would probably think that it is much too large. This is not so; for the bee actually enters the flowers and if he be watched on entering he will be found to touch the stigmas as he does so. There is just enough space for him to pass into the flower by so doing. (Fig. 437.) The stamens are ripe first in this flower and the pollen falls into the base of the bell where the honey is hidden. The bee becomes dusted with the pollen whilst gradually "working" round the base of the corolla to abstract the honey. The bells may be frequently found with holes pierced through them near their base. This is due to humble bees, who thus frequently rob flowers of their honey. (*See also under Columbine.*)

The ovary is completely embedded in the flower stalk in this flower. We shall find numerous examples of this in the

---

CANTERBURY BELL (*Figs. 434—438*).

Fig. 434.—Flower in Bud Stage.

Fig. 435.—Same in Longitudinal Section.

Fig. 436.—Same with Petals removed. *Fig. 437.—Open Flower.*

Fig. 438.—Same with part of Corolla cut away. (*p.*) Petals; (*sta.*) Stamens; (*w.sta.*) Withered Stamens; (*ov.*) Ovary. Note how the stamens are ripe in the bud stage, and how they are withered when the stigmas are unfolded

CHERRY (*Figs. 439—442*).

Figs. 439, 440.—Flowers in side view.

Fig. 441.—Flower with three of the Petals removed.

Fig. 442.—Flower cut down lengthways. (*f.s.* the cup-shaped Flower Stalk; inside which is the ovary (*ov.*), and on whose rim are the stamens (*sta.*), petals (*p.*), and sepals (*s.*).

study of complex flowers. *The phenomenon is thought to have partially arisen by flowers making a "tube" of their flower stalk and so gradually enclosing the carpels.*

7. **Cherry.**—(Figs. 439-442.) The cherry is a very good *example of the above. The honey is secreted at the base of the ovary, but to conceal it the flower stalk has been developed as a tube or cup bearing the sepals, petals and stamens on its rim.* (Fig. 442.)

From these examples it is clear that tubes are frequently produced by flowers, and also that they may utilise almost any part—sepals, petals, stamens, or flower stalk—for this purpose.

8. **Tobacco and Honeysuckle.**—*These two are grouped together because they agree in the following characteristics* :—

(*a*) They first open in the dusk of evening.

(*b*) They vary in colour from white to pale pink or yellow.

(*c*) They smell most strongly at night.

(*d*) They have very long tubular corollas.

Tobacco closes its petals in the day-time.

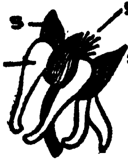
The above characteristics form very clear indications that these two flowers are specially adapted to pollination by the agency of large night-flying moths.

9. **Columbine, Larkspur and Monkshood.**—(Figs. 443-459.) These flowers are grouped together because they agree in that all their parts are separate from one another, their calyces are coloured, and their petals form nectaries.

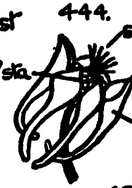
COLUMBINE (Figs. 443-448) is protected in the bud stage by greenish sepals, which turn bluish or pink in the open flower. The petals are also of the same colour, but each of these takes the form of a tubular nectary. (Fig. 444.) Humble bees frequently bite through the walls to get at the honey. Sometimes, however, we find flowers which may suggest that the plant has "endeavoured" to circumvent them, for several tubular petals are placed one within the other and a humble bee having bitten merely through one tube gains no nectar for his pains. (Fig. 445.)

LARKSPUR.—(Figs. 449-455.) This has also five coloured sepals. The posterior one of these is prolonged backwards into a tube. It has only four petals and these are small compared with the sepals. The two rear petals are prolonged backwards as long nectaries lying within the sepal tube. (Fig. 453.) This is a very ingenious way of

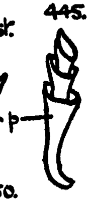
443.

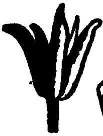


444.

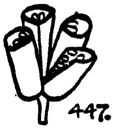


445.



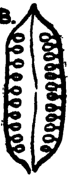


446.

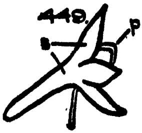


447.

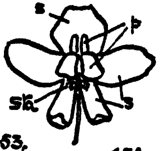
448.



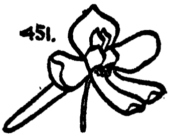
449.



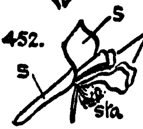
450.



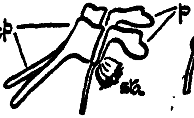
451.



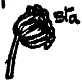
452.



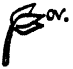
453.



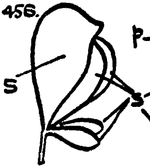
454.



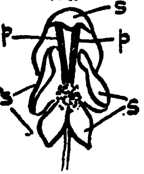
455.



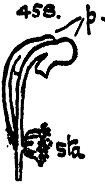
456.



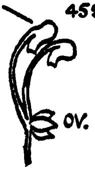
457.



458.



459.



COLUMBINE (*Figs. 443—448*).

Fig. 443.—Opening Flower. *Fig. 444.—Open Flower.* Note the tubular honey-containing petals.

Fig. 445.—Three Petals within one another.

Fig. 446.—A Group of Fruits produced from one Flower.

Fig. 447.—Fruits cut across, to show arrangement of the ripening ovules.

Fig. 448.—One Fruit opened and flattened out, to show its ripening ovules.

LARKSPUR (*Figs. 449—455*).

Fig. 449.—Complete Flower from the side. *Fig. 450.—From the front.*

Fig. 451.—From above sideways. *Fig. 452.—With four Sepals removed.*

Fig. 453.—After removal of the Sepals. *Fig. 454.—The Stamens.*

Fig. 455.—The Ovary. Note the spurred sepal and the two spurred petals.

MONKSHOOD (*Figs. 456—459*).

Fig. 456.—Flower from the side. *Fig. 457.—From the front.*

Fig. 458.—Sepals removed, to show the two-stalked nectaries (the petals).

Fig. 459.—Position of the Ovary.

hiding the honey. A glance at Figs. 450, 451 shows that only a very "intelligent" insect with a long tongue is able

(*a*) To find the entrance to the tube,

(*b*) To reach the honey drops lying at the base of the tube.

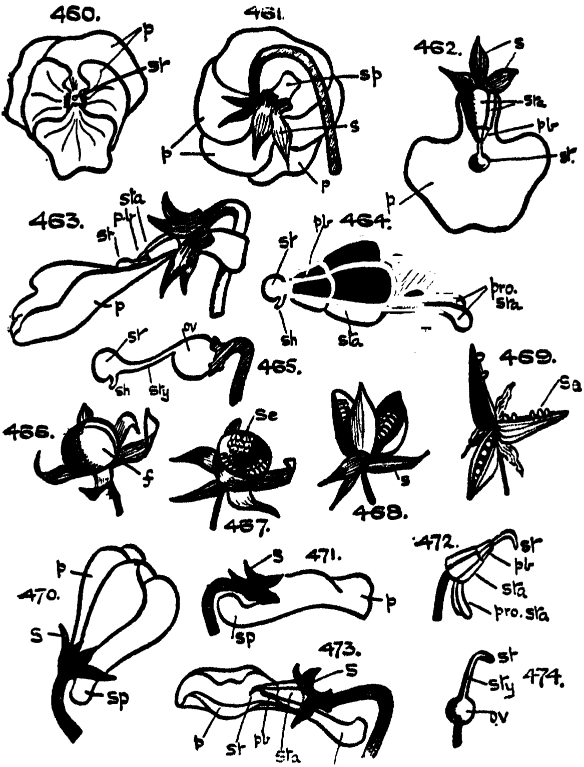
The reader should note from the figures how the essential organs (stamens and carpels) are placed in order that they may come in contact with the under surface of the bee's abdomen, and also how the front petals form a roof over the stamens to keep the pollen dry.

MONKSHOOD.—(Figs. 456-459.) We notice again a large coloured calyx, but here the corolla is represented by two strange-looking petals. They are stalked nectaries which lie closely under the curving hood. (Figs. 456-458.) The nectar is produced by the expanded ends of these two petals. The bee cannot reach the nectaries whilst on the wing; it must alight on the essential organs which are placed just at the right spot to be a most convenient landing place.

10. **Pansy and Violet.**—(Figs. 460-474.) These are two of the most "ingeniously" constructed British flowers. They possess a "cunningly" contrived pollen box which the bee necessarily opens, and the insect is dusted with pollen whilst obtaining the nectar. A careful study of the figures is necessary to get an idea of the structure of the flowers and their mechanism.

In the pansy (Figs. 460-469) the petals are streaked with coloured lines radiating from the "entrance" to the flower. These lines, which are sometimes called "pathfinders" or "honey guides," aid the bee in its search for honey. The front petal is prolonged backwards into a tube or spur containing two projections or nectaries, themselves parts of the stamens. (Fig. 463.) The stamens are five in number; their heads lie close together, and each is prolonged forwards to aid in the formation of an orange-coloured membranous pollen box into which the pollen falls as it is shed. The style runs through the middle of the box, and its stigma—a curious beaked head—lies beyond. (Fig. 464.) Study of the flowers shows that the stigma is the first part of the essential organs to be touched by the bee's head. It thus receives pollen brought by the insect from another pansy flower. The position of the receptive sticky surface is shown by the small depression in the stigma. (Fig. 465.)

The bee pushes its proboscis into the petal tube and, whilst



PANSY (*Figs. 460—469*).

Fig. 460.—Flower in front view. *Fig. 461.—Flower viewed from behind.*
Fig. 462.—Front view when all petals but the front one are removed.
Fig. 463.—Same from the side. *Fig. 464.—Last Petal removed.*
Fig. 465.—Stamens removed. *Fig. 466.—Fruit.*
Fig. 467.—Same in cross section. *Fig. 468.—Fruit bursting.*
Fig. 469.—Fruit withering and scattering the Seeds.

VIOLET (*Figs. 470—474*).

Fig. 470.—Flower viewed from the side.
Fig. 471.—Same with all Petals removed except the front one.
Fig. 472.—Same with all Petals removed.
Fig. 473.—Fig. 471 viewed obliquely from above.
Fig. 474.—Ovary.

Explanation of references :—(*s.*) Sepal; (*p.*) Petal; (*s.p.*) Spurred Petal; (*sta.*) Stamens; (*p.b.*) Pollen Box; (*pro.sta.*) Staminal Projections; (*st.*) Stigma; (*sh.*) Shutter; (*sty.*) Style; (*ov.*) Ovary; (*f.*) Fruit; (*se.*) Seeds.

probing there for the honey, moves the two staminal projections. This causes the lower part of the pollen box to be deranged and pollen consequently falls on the insect's head. In withdrawing from the flower, the bee closes the small beak or stigma flap so that there is no possibility of pollen from the same flower reaching the stigma.

The violet (Figs. 470-474) has precisely the same structure except that its receptive surface is the *front* part of the hooked stigma. This is untouched by the bee in withdrawing from the flower.

11. **Dead Nettle.**—This exceedingly common plant exhibits the following noteworthy structures :—

(*a*) The white-hooded petals protect the pollen from rain.

474 A

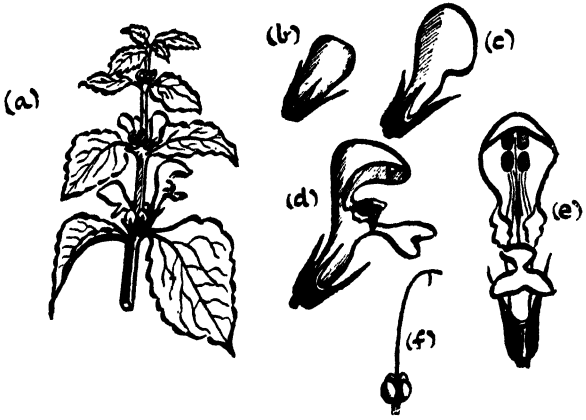


Fig. 474A.—STRUCTURE OF THE DEAD NETTLE.

(*a*) *General view of a Flowering Shoot.* Rings of flowers are borne just *above* each pair of leaves.
(*b*) and (*c*) *Flower Buds.*
(*d*) *Open Flower viewed from the side.* N.B.—The stigma hanging down just under the hood of the petals.
(*e*) *Open Flower viewed from the front.* Four stamens are seen within the hood and having the style between them.
(*f*) *Ovary of the Flower*, consisting of four small nut-like parts, with style as a long thread and a forked stigma.

(*b*) The smaller petals form a very convenient landing-place for the bee.

(c) The four stamens have stalks of two lengths, so that they all rub against the bee's back as it bends over to dip into the flower.

(*d*) The stigma hangs down between the stamens, and so is the first essential organ to come in contact with the bee.

(*e*) The honey is produced at the base of the petal tube.

(*f*) The lower part of the petal tube is closed by hairs, a formidable obstacle to the passage of small insects.

(*g*) The plant economises its material by producing its stamens some distance up the petal tube.

The last phenomenon is very widespread among these more highly developed flowers.

12. **Comfrey and Snapdragon.**—We group these two bee flowers together because they protect the pollen very thoroughly from rain.

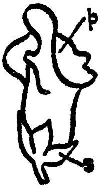
COMFREY.—In comfrey (Figs. 480-483) there are five outgrowths from the petals which completely roof in the stamens lying below. The style projects well out from the flower, but no insect can reach the honey lying at the base of the tube unless it be strong enough to push aside the "segments" of the "pollen box." (Fig. 481.) This is an interesting case of the tendency rigidly to exclude all intruders.

SNAPDRAGON.—Figs. 475-479 afford us another example of this, but here the petals themselves form a strong box whose lid can only be opened by a strong insect. (Fig. 475.) These mechanisms in comfrey and snapdragon exclude all insect visitors save bees.

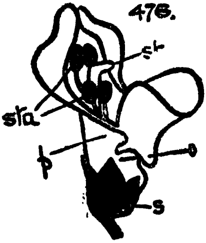
13. **Primrose** (Figs. 484-486).—In this flower both the sepals and the petals are combined into tubes. The stamens have exceedingly short stalks, but this disadvantage is obviated by their attachment to the corolla tube, by which contrivance they are placed either half-way down the tube or at its mouth. (Figs. 485, 486.) On examination we find either a group of stamens or a green sticky stigma occupying the entrance to the flower; these two arrangements have given rise to the erroneous rural idea that there are male and female primroses.

Darwin, that most patient of investigators in Natural Science, subjected primroses to a long series of experiments, from which he drew the following most significant conclusion: "If pollen be transferred from a long stamen to a long stigma, or from a short stamen to a short stigma, there are more seeds and healthier offspring produced than those which result

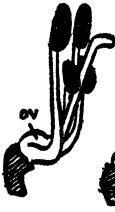
475.



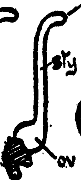
476.

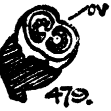


477.



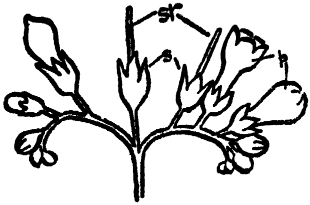
478.



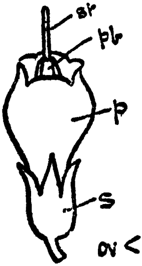


479.

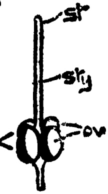
480.



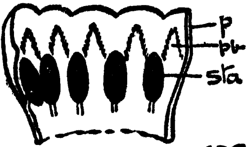
481.



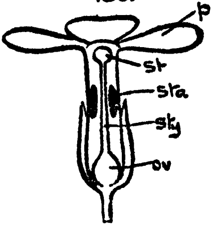
483.



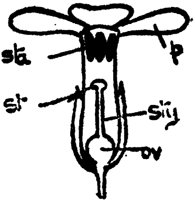
482.



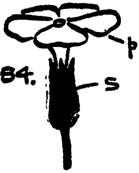
485.



486.



484.



SNAPDRAGON (*Figs. 475—479*).

Fig. 475.—General view of the Flower.
Fig. 476.—The Flower pinned open, showing the position of stigma and stamens.
Fig. 477.—Relative positions of Stigma and Stamens.
Fig. 478.—The Ovary.
Fig. 479.—Ovary cut across, showing two chambers and many ovules.

from the transmission of pollen from a stamen to a stigma of different length." Since the former case involves cross-pollination, as will be seen by reference to Figs. 485, 486, it follows that this is more advantageous to the plant than self-pollination.

14. **Sunflower.**—(Figs. 487-499.) This, our last example, is remarkable both for the economical way in which the plant utilises the material available for flower construction, and the certainty with which pollination is effected. To begin with, a sunflower is not a single flower, but a whole mass of flowers. The leaf-like parts surrounding the head of flowers render individual calyces unnecessary, and these are practically absent—a saving in material. Again, the individual flowers are very small, and would be very inconspicuous were not the outer flowers possessed of long strap-shaped corollas. These hundreds of small flowers gain a conspicuity which they would lack otherwise. A further advantage is that one insect visitor is able to pollinate a large number of flowers at a single visit.

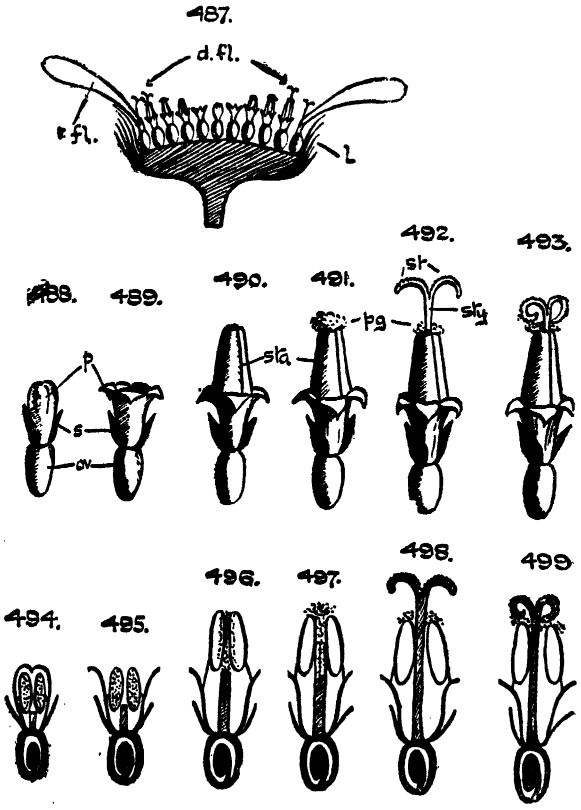
Coming now to the structure of the individual flowers, we find the ovary as a spherical mass low down in all the flowers, whether strap-shaped or not. The corolla springs from this, and in the central flowers it is a small tube with five small teeth at its rim; in the outer flowers it is a short tube very soon prolonged into the yellow strap. (Fig. 487.) Young flowers in the bud stage occupy the centre of the flower head, and by examining in turn flowers lying further from the centre we can trace the appearance and function of the essential organs. First the corolla bursts, and a black tube made of five combined stamen heads projects from it. The tip of this is soon seen covered with yellow pollen dust. If we wipe away the pollen from a selected flower, we find on subsequent examination that it again has pollen at its tip. Evidently the pollen is being forced out.

COMFREY (*Figs. 480—483*).

Fig. 480.—Collection of Flowers. Note all stages of opening.
Fig. 481.—One Flower in detail. (N.B.—The pollen box around the style.)
Fig. 482.—The Corolla spread out to show the position and parts of the Pollen Box. Imagine this flattened corolla curved into a tube and note how the five conical hairy projections form the hollow pollen box, which can be seen in *Fig. 481.*
Fig. 483.—The Ovary, consisting of four nut-like parts.

PRIMROSE (*Figs. 484—486*).

Fig. 484.—Complete Flower.
Figs. 485, 486.—Two Flowers, with Petal Tubes cut down, to show varying positions of stamens and stigmas.
Fig. 485.—Long Style and short Stamens.
Fig. 486.—Short Style and long Stamens.
Most seeds (and most healthy offspring) are produced when pollen is transferred from a stamen to a style of the *same* length.



SUNFLOWER (*Figs. 487—499*).

Fig. 487.—Head of Flowers cut through vertically. (*r fl.*) Ray Flowers; (*d.fl.*) Disc Flowers.

Figs. 488—493.—Series of Disc Flowers, to show the order of opening and the floral mechanism.

Figs. 494—499.—A series of longitudinal sections, at precisely the same stages. (An ovule can be seen in each ovary.)

As a matter of fact the style is gradually growing up in the centre of the flower and, acting like a piston, is forcing out the pollen little by little.

This is, indeed, an ideal way of presenting the pollen so that it may be exposed to insect visitors for a long time.

At last the style emerges from the stamen tube. It grows some distance and then unfolds its two stigmas. Really, the latter were at the tip of the style while it was pushing out the pollen, but they were pressed close together lest any pollen should touch their inner receptive surfaces. (Fig. 497.)

Plate I.—A Blaze of Bloom (Rhododendrons).

The flower, with expanded stigmas, has now reached the female stage and is ready to receive pollen. If the stigmas are not successful in having pollen placed upon them they curl up during withering and so come in contact with the pollen which has been left at the tip of the stamen tube. (Fig. 493.)

This is the best possible example of a flower catering for cross pollination, yet resorting to self pollination if necessary.

It should be noted that no stamens will be found in the strap flowers of the sunflower. This almost suggests that the "strap" has been developed at their expense.

15. **Wind versus Insect Pollination.**—By the use of either of these methods, cross pollination is attained, and we have already seen that the latter is advantageous to the plant.

THE PLANT HAS TO PAY A PRICE FOR THIS ADVANTAGE. In wind pollination there is great waste of pollen, thousands, we may say millions, of pollen grains never reaching the stigmas. On the other hand the flowers can be small and inconspicuous, the wind being a perfectly "impartial" agent.

With insect pollination a great economy in pollen production is effected, yet various expensive attractions must be provided to ensure insect visits. It will be well to tabulate here the characteristics of wind and insect pollinated flowers.

Wind Pollinated Flowers.	**Insect Pollinated Flowers.**
(*a*) Large or numerous stamens.	Fewer stamens.
(*b*) Abundance of pollen.	Very little waste of pollen.
(*c*) Powdery pollen.	Pollen frequently coheres in masses.
(*d*) Protection of pollen from wet.	Pollen usually protected.
(*e*) Freely projecting stamens.	Stamens lie within the flower.
(*f*) Delicate stamen stalks.	Sturdy stamen stalks.
(*g*) Long stigmas.	Short stigmas usually.
(*h*) Stigmas feathery or bushy.	Stigmas frequently papillose.
	Long style often acts as the stigma-presenting organ.
(*j*) Small flowers.	Flowers large as a rule.
(*k*) No gaudy parts.	Attractive coloured petals.
(*l*) No honey produced.	Honey usually produced.
(*m*) No scent produced.	Scent frequently produced.
(*n*) Flowers produced before the unfolding of the leaves.	Flowers produced when insects are numerous.
(*o*) No tubular structures present.	Tubes produced to fit flowers for particular insects.
(*p*)	Many additional mechanisms.

SUMMARY.

COMPLEX FLOWERS AND THEIR MECHANISMS.

The Lengths of Tongue in Insects:—

Short tongues—less than 6 mm. (small flies, beetles, bees and moths).

Long tongues—greater than 6 mm. (large bees, moths and butterflies).

The Parts Forming the "Tube" in Flowers.

Upright sepals, *e.g.* Wallflower.

Combined sepals, *e.g.* Pink.

Combined petals, *e.g.* Canterbury Bell, Sunflower, etc.

Combined stamens, *e.g.* Hollyhock, Pea, Bean, Laburnum, Clover.

Flower stalk, *e.g.* Cherry.

Special Mechanisms. Note the following:—

SWEET PEA—action of standard, wings, and keel.

CANTERBURY BELL—width of entrance between petals and stigmas.

TOBACCO AND HONEYSUCKLE —Moth flowers. Colour— times of flowering and strong scent—length of tube.

COLUMBINE, LARKSPUR, MONKSHOOD—petals are the nectaries.

PANSY AND VIOLET—pathfinders—the pollen box—prevention of self pollination.

DEADNETTLE, COMFREY, SNAPDRAGON—exclusion of intruding insects.

PRIMROSE.—Different lengths of style and stamens.

SUNFLOWER—economies effected—piston-like mechanism of the style—*long* chance of cross-pollination, with a *last* chance of self-pollination.

Characters of Wind and Insect-Pollinated Flowers—see Summary in Section 15.

PRACTICAL.

1. **Dissect and sketch as many flowers as possible.**
2. **Mentally reconstruct in detail an insect's visit to the flower you are examining.**
3. **Measure the length of tube in the flower—Decide which visitors are catered for.**
4. **Study insects visiting garden and wild flowers.**
5. **Time a bee in its flower visits.**

   How long does it stay at one flower?

   How many flowers does it visit per minute?

   Does it visit flowers indiscriminately or does it confine its attention to one particular kind of flower?

   Give the reasons for what you observe.
6. **Keep a list of the flowers you study in garden or field, noting the date, the number of visitors, the kinds of visitors.**

CHAPTER XVIII.

Formation of Seeds and Fruit and their Dispersal.

When the male cell has succeeded in fusing with the egg cell of the ovule a great stimulus is thus given, with the result that the ovule develops into a seed and the ovary (or carpels) into the fruit wall or seed vessel. Seeds have been fully studied in an earlier chapter; but there remains for us to take a general survey of the carpel development and the various mechanisms of fruit and seed dispersal.

The seed itself may have its external coat modified into fluffy or winged dispersal organs, but in the vast majority of cases it is the carpellary wall which undergoes the greatest modifications. Increase in size of the carpels is a uniform accompaniment to their later development; this is consequent upon the ovules growing very much during transformation into seeds. The carpels may be modified in any one or several of the following ways:—

(*a*) They may become membranous (*e.g.* apple);

(*b*) Membranous within and juicy without (*e.g.* bean);

(*c*) Woody, fleshy and membranous in their inner, middle and outer regions respectively (*e.g.* cherry);

(*d*) Woody throughout (*e.g.* nuts);

(*e*) Fleshy, with an outer skin (*e.g.* berries);

(*f*) Hairy (*e.g.* geranium, clematis);

(*g*) Winged (*e.g.* sycamore);

(*h*) Brightly coloured (*e.g.* berries).

The flower stalk frequently develops to form a juicy attractive part of the fruit (rose, apple). Other parts of the flower may furnish fluffy dispersal contrivances (*e.g.* the calyx in dandelion and thistle).

1. **Dispersal of Seeds and Fruits.**—Our previous considerations of vegetable life have emphasised the facts that a plant, in order to have healthy vigorous life must be adequately supplied with:

(a) Water and mineral salts;
this presupposes a sufficient region of soil in which the roots may ramify.

(b) Carbon dioxide,
to be synthesised with water to form sugar.

(c) Light,
in order that the above food elaboration may be performed.

(d) Oxygen,
for breathing purposes.

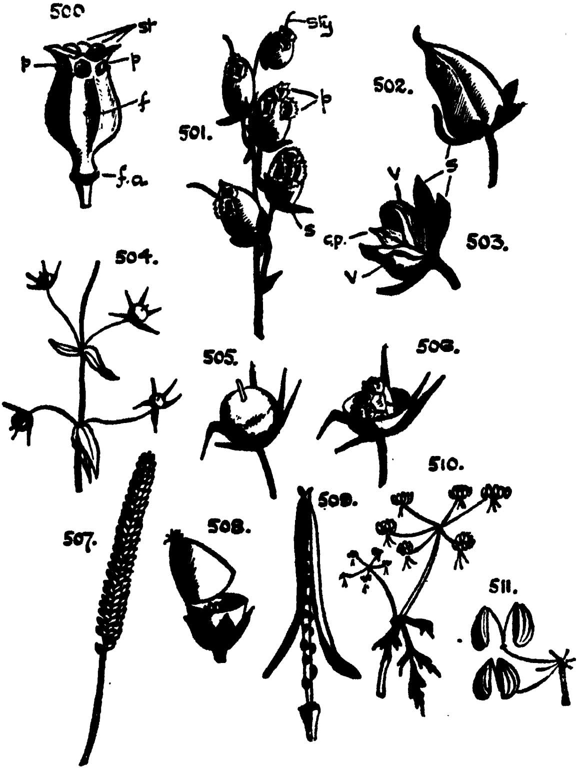
Since the above conditions can best be attained when the plant is growing at some distance from others, it follows that a thorough dispersal of the seed is necessary.

If all the seeds were to fall to the ground immediately beneath the parent, the natural consequence would be that a numerous crop of unhealthy seedlings would be produced, for neither the ground nor the air would afford them sufficient sustenance. Hence it is of the utmost importance that a full provision should be made for scattering the young plants whilst still contained in the seeds. Many plants scatter their seeds whilst the latter are still enclosed in the seed cases or fruits, but since the principles involved are largely the same in the two cases, seed and fruit dispersal will be treated together in this chapter. It is sometimes hard to determine whether the seed is being dispersed alone or in its seed vessel (the fruit). The distinction will be clearly drawn in the examples quoted below, and drawings of the flowers from which the fruits have developed will be given wherever such are deemed helpful.

There is no part of Plant Biology which better illustrates the use of varied means to the same end than this question of seed dispersal, and the adoption of such various contrivances only emphasises how keenly plants have struggled against one another in the competition for light, air and soil.

When once the idea has been grasped that plants seen to-day only exist because their ancestors successfully held their own against multitudinous competitors, the student has gone far towards understanding the main dispositions of vegetation into communities (See Chapters xxi.-xxiii.).

To aid the seed dispersal, plants generally utilize outside agents, such as wind, animals and water.



SOME WIND-BLOWN SEEDS (*Figs. 500—511*).

Fig. 500.—Poppy Capsule. (*st.*) Radiating Stigmas forming eaves over the pores (p.) of the fruit (*f.*); (*f.a.*) Place of attachment of the other floral organs.

Fig 501.—Snapdragon. Group of capsules, each has three pores (*p.*) with fringed margins; (*sty.*) Withered Style.

FOXGLOVE CAPSULE (*Figs. 502, 503*).

Fig. 502.—Unripe Capsule.

Fig. 503.—Burst Capsule. The case bursts by two valves (*v.*) leaving a central membrane (*c.p.*), which was a partition between the two chambers of the ovary.

PIMPERNEL (*Figs. 504—506*).

Fig. 504.—Small Twig with Capsules.

Fig. 505.—One unripe Spherical Fruit.

Fig. 506.—The burst condition, showing the seeds as a central mass.

2. **Wind Dispersal.**—For wind dispersal lightness is essential. This is often obtained by the extremely small size of the seeds. Many of the weeds which so persistently appear in our gardens are carried thither by the wind, and their successful transport is largely due to the smallness of their seeds. A very good experiment in this connection is to weed thoroughly a small plot of land and let it lie quite free for such visitors. One such small plot was found by the writer to be occupied by over twenty different plants within two months, and some of the seeds were traced to have travelled a considerable distance.

Where the seeds are so very small, they are frequently so placed in the plant that they are only freed during a strong wind.

3. **Seeds Freed by a Strong Wind.**—The poppy fruit (Fig. 500) is a very good example of this. The powdery mass of seeds enclosed in the seed vessel only escapes when the upright case is violently shaken by the wind. Note also here now the seeds are kept dry by the overhanging " eaves " of the fruit until they are dispersed.

Similar considerations apply to the seed boxes of mullein, snapdragon (Fig. 501) and foxglove (Figs. 502-503).

The little pimpernel (Figs. 504-506) whose scarlet flowers so often brighten the gray stones of an old wall, cuts off the upper part of its globular fruit, as a hemispherical lid, whereupon the seeds easily fall to the ground. (Fig. 506.)

The plantain (Fig. 508) scatters its seed in a similar way, but these seldom fall to the ground near the parent, for they remain in the cuplike case until a stiff wind shakes the sturdy upright fruit stalk.

Wallflower fruit (Fig. 509) first splits up from the base in two long valves, leaving the seeds attached to a membranous partition, until either they fall or are blown away. The " purses " of shepherd's purse behave similarly.

The hemlock and parsley (Figs. 510, 511) split their carpels into one seeded portions, each of which remains attached to the plant by a slender thread. A ripe hemlock head of fruits always shows these dangling in pairs ready for removal by the

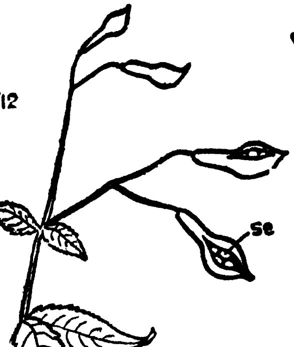
PLANTAIN (*Figs. 507, 508*).

Fig. 507.—Long Spike of Fruits.
Fig. 508.—One Fruit bursting and showing the seeds left within the cup.
Fig. 509.—Wallflower. The fruit bursting upwards by two valves, leaving the seeds attached to the central partition.

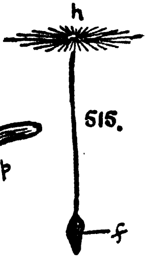
WILD PARSLEY (*Figs. 510, 511*).

Fig. 510.—Heads of Fruits.
Fig. 511.—Details of the bursting of two Fruits. A slender strand fastens the dangling fruit until it is blown away by the wind.

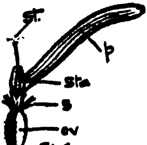
512



513.

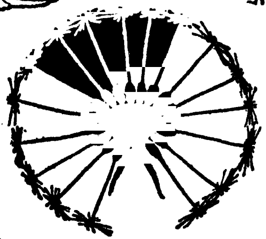


515.



514.

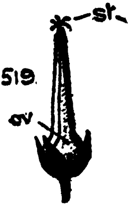
516.



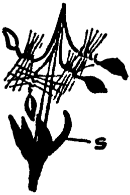
517.

518.

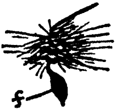
519.



520.



521.



522.

EXPLOSIVE SEED-PODS (*Figs. 512, 513*).

Fig. 512.—Balsam. Fruiting Twig. The two lower capsules are just bursting.

Fig. 513.—Lupin. The pod burst and twisted.

"PARACHUTE" SEEDS (*Figs. 514—522*).

Fig. 514.—A Single Dandelion Flower. Note that the sepals are merely represented by a few hairs (*s*).

Fig. 515.—One Parachute Fruit. The hairs (*h.*) have been developed from the calyx.

Fig. 516.—Longitudinal section through a Dandelion "Clock" or Head of Fruits.

Fig. 517.—Single Fruit of Thistle. The hairy tuft (as also in *groundsel, Fig. 518*), has been developed from the calyx.

wind. Each fruit is a disc, whose flattened shape enables it to be carried much further before it reaches the ground.

The groups of tiny nuts produced by the deadnettle are similarly scattered. The white-hooded corolla of the flower withers and falls away. The four nuts remain at the bottom of the small calyx cup, until the plant is moved from its upright position, either by the wind or by some passing animal.

Many plants having pod-like fruits scatter their seeds in a like fashion. Thus, the fruit of larkspur, columbine and marsh-marigold open down one side only. The seeds when ripe fall from their stalks into the bottom of the open pod, and require a strong shake before being scattered.

In the above-mentioned plants the force of the wind carries the seeds to a moderate distance from the parent, but sometimes the latter itself provides a propulsive mechanism.

4. **Seeds Forced Away from the Plant.**—The violent dispersal of the seeds of the common balsam will be familiar to most readers. The fruit just on the point of bursting is shown in Fig. 512. The bursting of the fruit and the flight of the seeds is so sudden that the eye cannot follow the latter in their movement. If you touch the tip of a ripe balsam fruit, there is a sharp report and instantaneously the fruit is empty.

Another plant whose fruit bursts violently is the gorse or furze. If you are in the neighbourhood of furze bushes on a hot summer day, you may hear again and again the sharp crack of the pods and the rattling of the seeds, like a miniature artillery.

The violet or pansy, on the other hand, furnishes a good example of a fruit whose slow drying and shrivelling causes a forcible ejection of the seeds. When ripe, the pansy seed case bursts into three valves, and on the centre of each of these there are some twenty or thirty seeds. (Fig. 468.) If the fruit be kept under observation it will be found slowly to assume the appearance shown in Fig. 469.

In the gradual drying of the valves the sides move upwards and thus press against the seeds, the latter being "flirted" a distance of several yards in precisely the same way in which an orange pip may be shot from between the thumb and finger tips.

If a gardener wishes to secure pansy seeds he must either cover the plants, or visit them at intervals in order to gather the fruits immediately after they have burst. The lupin exhibits a similar mechanism after the pods have burst, each of the two valves gradually curls into a spiral during the drying process. The seeds are pressed upon in this way and are smartly forced away from the parent. (Fig. 513.)

One of the strongest explosive mechanisms is found in the wood sorrel. In this plant the seeds themselves furnish the motive power. Each seed is covered by an outer coat of a highly elastic nature. When ripe this elastic coat breaks away at one point, and its sudden contraction is so strong that it completely turns the seed inside out. This force is sufficient both to break the seed case and to propel the seeds a considerable distance.

5. **Seeds and Fruits of a Hairy Nature.**—The feathery nature of many seeds (and fruits) is perhaps the contrivance most familiar to every reader. The object of such hairiness is to increase the buoyancy of the seed (or fruit), so that it may be a longer time in falling to the ground, and consequently that it may come to rest at a greater distance from the parent than it otherwise would have done.

We will first deal with fruits scattered in this way. In dealing with such fruits as those of dandelion, groundsel, and thistle, it is necessary to bear in mind the structure of the flowers.

It should be noted at the commencement that dandelion, daisy, groundsel, thistle, and all "flowers" of a similar nature, are not single flowers at all, but masses of flowers. Every yellow "strap" in the dandelion head is a separate flower. Each contains petals, stamens, and an ovary. The only part missing is the calyx. Yet this is only apparently missing, for it is represented by a few hairs just above the ovary. (Fig. 514.) Note particularly the ovary and the hairs above.

When the flowers have been pollinated, the dandelion head closes up in order to protect the developing fruit lying within. If the dandelion happens to be an intruder on the lawn and frequent mowing has given it a stunted habit, its flower heads scarcely project from the ground level.

On the ripening of the fruits, however, a rapid growth in length of the stalk takes place. The head is carried well up into the air, the leaves investing the fruits are lowered and the beautiful downy ball is fully exposed to the wind. The fruits are aggregated on a central stalk. From a central mass of fruits there radiate with perfect regularity numerous stiff threads, and each of these bears at its outer end a perfect "wheel" of down. (Fig. 516 and Photograph, page 281.)

We are apt to despise the dandelion "clock," but it is really one of the daintiest examples of symmetry furnished by nature.

Fig. 515 shows one isolated fruit. A comparison with the flower in Fig. 514 makes it quite clear that the whole of the parachute mechanism has been developed from the few hairs which represent the calyx.

The thistle and groundsel (Figs. 517, 518) furnish their fruits with hairs in much the same way: the main difference being that the tuft of hairs is borne directly on the tip of the fruit, and not carried aloft by a long thread as in the dandelion. The garden geranium (Figs. 519-522) provides its fruits with a hairy tuft in a far different way. On looking into the centre of the flower, five small stigmas can always be seen on the tip of the ovary. On ripening, five one-seeded fruits curl up from a central stalk. The inner part of the fruit is hairy and these hairs are formed into a "wheel" by the upper region becoming a close spiral. (Fig. 520 *et seq.*) It is very instructive to compare the flower's method of "parachute" formation with that of the dandelion, and to see how the same end is attained by different means.

The clematis (old man's beard or traveller's joy) climbs through the hedges by means of its leaf stalk tendrils, so that its woolly balls of fruits are well exposed to the wind in the autumn. Each single fruit has a long hairy thread at its tip. This long structure has been produced from the style of the ovary. It makes the fruit exceedingly light. (Figs. 523-525.)

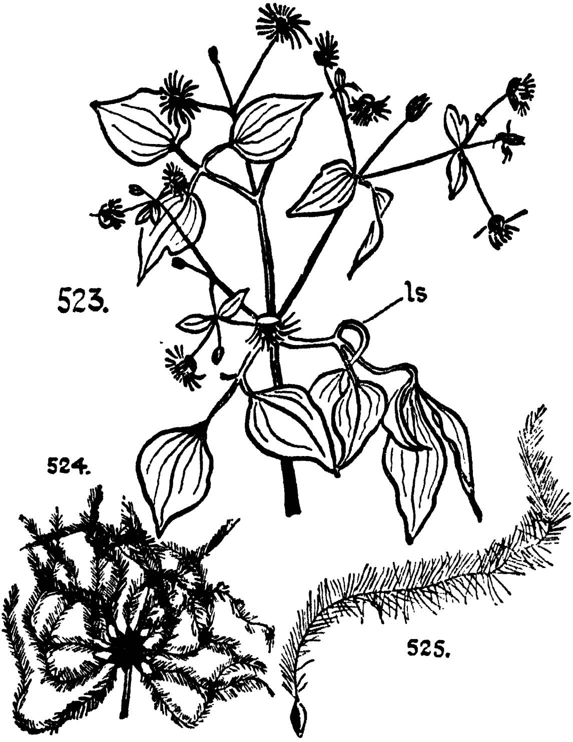
The above plants have hairy fruits. We will now consider hairy seeds.

The fruits of willow and poplar were given in Figs. 374, 379. Reference to these will show that the hairy mass comes from within the ripened carpels. The seeds are scattered by the wind, the seed vessels remaining attached to the parent for a much longer time.

The willow herb (Figs. 526-529), a tall plant, whose pink flowers brighten many a brook side, also produces fluffy masses of seeds. Each flower has a long ovary, so long in fact that it looks like the stalk of the flower. (Figs. 526, 527.) After the petals and other floral parts have fallen, the ovary often grows until it reaches three inches or so in length. Finally, it bursts into four narrow downward curling parts, and a ball of down is freed. Each seed in this ball has a hairy tuft at its tip (Figs. 528, 529.)

6. Winged Fruits.—Many familiar trees have winged fruits: one—the pine—produces winged seeds. The advantage from prolonging the fruit into a wing is the same as that accruing from its modification into a feathery structure, *viz.* an increased buoyancy, and, consequently, a germination more distant from the parent.

Sycamore (Figs. 534, 535) gives a good example of a double winged fruit. When ripe the two halves fall off separately,



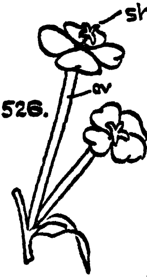
Clematis (*Figs. 523—525*).

Fig. 523.—Flowering Branch. A leafstalk tendril is shown at (*l.s.*). Each flower has many petaloid stamens, with broad white stalks.

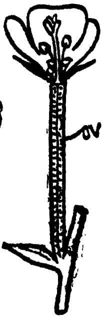
Fig. 524.—A Flower in the Fruiting Stage. Each separate fruit (*Fig. 525*) has a long feather. This has been developed from the style of the carpel. (Compare the collection of fruits with those of buttercup, blackberry and strawberry.)

Fig. 525.—An Isolated Fruit.

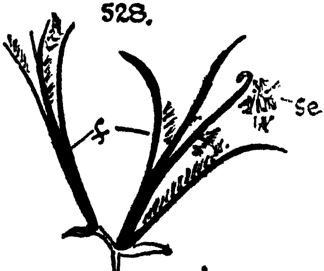
526.



527.

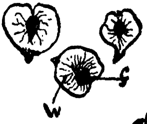


528.

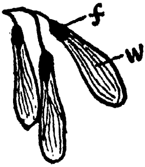


529.

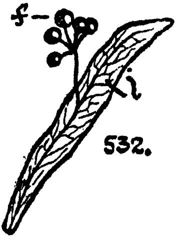
530.



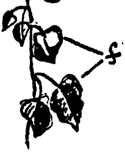
531.



532.



533.



WILLOW HERB (*Figs. 526—529*).

Fig. 526.—Flowering Twig. The apparent stalk (*ov.*) of the flower is really the Ovary.

Fig. 527.—The Flower in longitudinal section. (*ov.*) Ovary with numerous ovules.

Fig. 528.—Two Flowers in Fruiting Stage. Hairy seeds are escaping from the slender split capsules.

Fig. 529.—One Seed magnified to show its hairy tuft.

SOME WINGED FRUITS (*Figs. 530—533*).

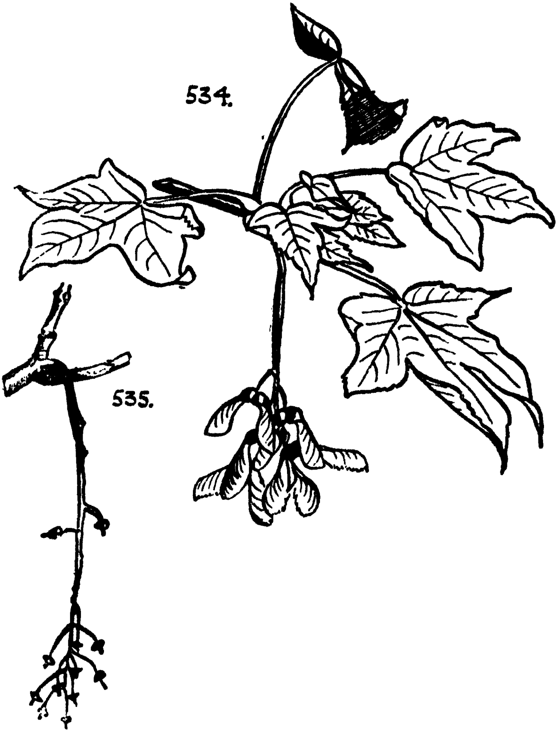
Fig. 530.—Elm Fruits. (*f.*) Fruit; (*w.*) Wing.

Fig. 531.—Ash Fruits.

Fig. 532.—Lime Fruits. (*f.*) Nut-like Fruits; (*l.*) Leaf to which they are attached.

Fig. 533.—Dock Fruits. The perianth enlarged to form the three wings which invest the small nut.

and the fruit stalks are left behind on the tree, where they may remain for two years or more. One pendulous cluster of sycamore flowers will enable the student to see all stages in the development of the fruit and its wings. (Figs. 393-396.)



SYCAMORE (*Figs. 534, 535*).

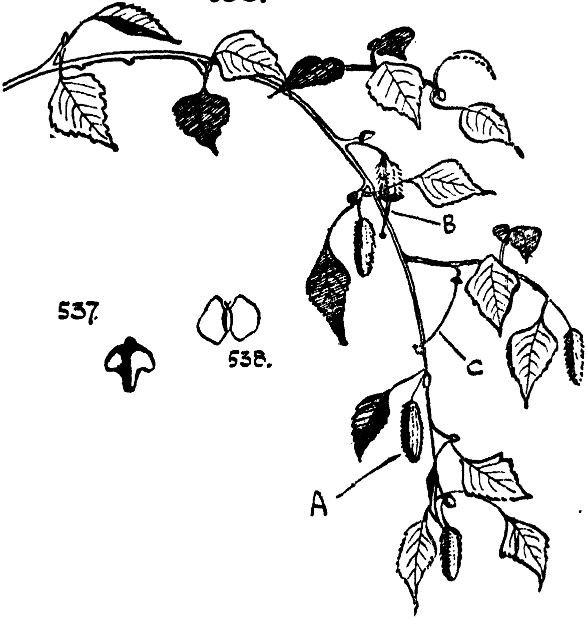
Fig. 534.—Fruiting Branch. Each fruit has two wings.
Fig. 535.—Old Fruit Stalks left from previous year.

Elm and ash fruits (Figs. 530, 531) differ from sycamore in that a single membranous expansion is produced.

The birch (Figs. 536-538), itself the most graceful of our English trees, produces three delicate winged fruits within each scale of its female catkins. The scales are so closely packed together that the little "butterfly" fruits are only released when the catkin falls to pieces. Our specimen (Fig. 536) shows all stages in the falling away of the catkin scales.

Each small fruit bears a remarkable resemblance to a butterfly: there are wings, body, and antennae, the "wings" are outgrowths from the ovary (*i.e.* the "body"), whilst the "antennae" are the remains of the two stigmas.

536.



537.

538.

BIRCH (*Figs. 536—538*).

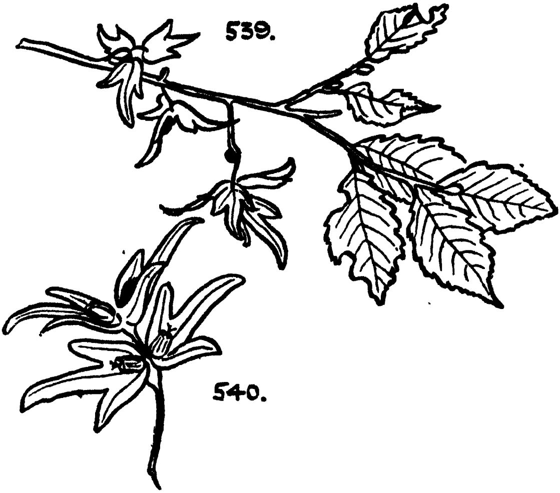
Fig. 536.—Fruiting Branch. Various stages in the disintegration of the catkin are seen (A.B.C.).

Fig. 537.—One Scale fallen from the Catkin.

Fig. 538.—One of the three small Butterfly-shaped Fruits which lie upon each Scale.

The hornbeam (Figs. 539, 540) scatters its nuts by partially enclosing them by the base of a large three lobed leaf-like scale. Nut and scale fall off together. Young hornbeam plants may often be found growing ten to twenty yards from the parent.

The lime (Fig. 532) scatters several fruits together by means of the leaf-like part to which their main stalk is attached. The little hard balls should be cracked and their enclosed seeds carefully examined. They will each be found to contain a plantlet having two seed leaves, but this is embedded in a relatively large amount of extra nutriment. Contrast this with bean and acorn structure.



Hornbeam (*Figs. 539, 540*).

Fig. 539.—Fruiting Branch.
Fig. 540.—Details of the Nuts and Scales.

The dock (Fig. 533) has for its fruits small triangular nuts, which would fall vertically to the ground were it not that the perianth persists and invests them with three projecting wings.

SUMMARY.

Fertilization results in the formation of a seed from the ovule and a fruit from the ovary.

In seed development a young plant is produced from the egg cell, and the ovule coat develops into the seed coat.

In some cases the seed coat becomes hairy or winged. The ovary becomes greatly modified: it may grow into a hairy, skinny, fleshy, woody, coloured, or prickly structure.

Necessity for Seed Dispersal.—To ensure sufficient light and raw food materials for the plantlets.

Wind Dispersal.—Lightness is obtained by:—

(*a*) Small seeds (*e.g.* poppy);

(*b*) Flat fruits (*e.g.* hemlocks, buttercups);

(*c*) Winged fruits or seeds.
  The wing is:—
    1. The carpel wall (*e.g.* sycamore, birch, ash).
    2. The perianth (*e.g.* docks).
    3. Leaf-like parts (*e.g.* hornbeam, lime).
    4. Seed coat (*e.g.* pine).

(*d*) Hairy fruits or seeds.
  The hairs are:—
    1. Calyx (*e.g.* dandelion).
    2. Style (*e.g.* clematis).
    3. Inner part of ovary (*e.g.* geranium).
    4. Seed coat (*e.g.* willow, poplar, willow herb).

Strong Wind is Necessary in poppy, snapdragon and the other upright seed vessels.

Explosive Mechanism in pansy, furze, balsam, woodsorrel.

PRACTICAL.

1. Examine, dissect and sketch as many fruits as possible.
2. Measure the distances that young plants are found growing from their parents.
3. Study the seeds and dispersal mechanisms of plants you find growing—
   (*a*) Between the stones of an old building;
   (*b*) On the tops of decayed tree trunks still standing upright.
   Account for these plants occupying such positions.
4. Gather as many wind-scattered fruits as possible. Note the date of dispersal of each. Correlate the extent of wing with the intensity of winds generally prevalent at the particular season.
5. Examine elm fruits for contained seeds.
   Can you account for their immature nature or complete absence?
6. Make a series of drawings to illustrate the development of the fruits from the flowers of geraniums, clematis and pansy.

CHAPTER XIX.

Dispersal of Fruits and Seeds (*Continued*).

1. **Dispersal by Animals.**—Plants cater for their fruit dispersal by animal agents in two main ways: (1) they either make the outer part of the fruit prickly so that animals may unwittingly carry it long distances attached to their bodies, or (2) the fruit is edible and made additionally attractive by size or by colour. In many plants large coloured, edible fruits are the rule, but usually special contrivances are devised to prevent the essential plantlets being consumed.

2. **Prickly Fruits.**—These are uniformly inconspicuous both in size and colour. The Geum plant (Figs. 541-546) furnishes our first example. The garden species of this plant shows the structure much better than the wild one (the wood avens), so the present description applies to the former. If the flowers be examined, a very close resemblance to a buttercup will be found:

The ovary, which like that of the buttercup consists of many separate carpels, is chiefly noteworthy because of the peculiar shape of its styles and stigmas. Each style bears the

---

BURDOCK (*Figs. 547, 548*).

Fig. 547.—Three Fruits. *Fig. 548.—One separate Fruit.*
The leaves investing the head of flowers form a hooked coat to aid dispersal.

AGRIMONY (*Figs. 549, 550*).

Fig. 549.—Spike of Fruits. *Fig. 550.—One separate Fruit.*
Note how the burr hooks form a conical projecting region, and are in the best position for coming in contact with animals.

CALVARY CLOVER (*Figs. 551, 552*).

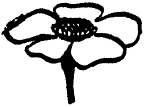
Fig. 551.—The Pod in its naturally close coiled state.
Fig. 552.—The same opened out, to show the thorny development of the pod-wall.

Fig. 553.—Cherry. Fruit in longitudinal section.

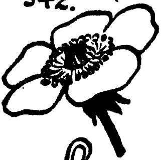
Ovary wall = { (*s.*) Skin. (*p.*) Pulp. (*st.*) Stone.

(*s.c.*) Seed Coat; (*se.*) Seed.

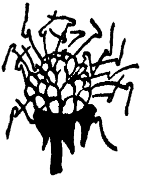
541.

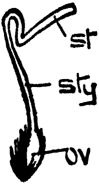


542.



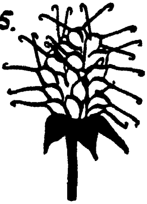
543.

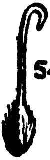




544.

545.





546.

549.

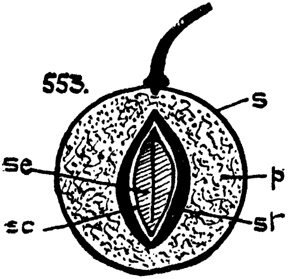
548.

547.

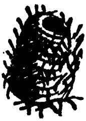
550.

552.

553.



551.



GEUM (*Figs. 541—546*).

Fig. 541.—Early stage of the open Flower. Stamens only are seen in the centre of the flower.
Fig. 542.—Later stage of flowering. The stamens form a wide ring, and the centre of the flower is occupied by the styles and stigmas of many carpels.
Fig. 543.—Early stage of Fruit development. Each style has a stigma almost at right angles to it.
Fig. 544.—One such Carpel. (*ov.*) Ovary; (*st.*) Stigma; (*sty.*) Style.
Fig. 545.—Ripe Fruit. *Fig. 546.—One isolated Fruit.* Note the hook left by the falling of the stigma.

stigma projecting from it at a sharp angle. When the fruit is ripe the stigmas fall off and leave the style tipped with a sharp hook. (Figs. 543-545.) The fruits very easily separate from one another and cling with great tenacity to the clothing of human beings or the fur of animals. An interesting fact is that these prickly fruits, especially in the wild geums, lie very close to the ground and are thus placed in the most likely position for contact with animals.

Another plant with prickly fruits is "cleavers," whose slender stems and rings of leaves can be seen in most hedgerows. The ripe fruit consists of two green balls covered with minute hooks, and these very easily become detached from the parent. A person frequently brings home from an Autumn ramble specimens of this fruit attached to his clothing. The whole plant is covered with these recurved hooks. It is by means of these that it climbs through a hedge.

Do any other plants climb in this way?

The Burdock (Figs. 547, 548) invests its head of fruits with an external covering of sharply-hooked leaves. These leaves originally performed the same function for the flower head as those around dandelions and daisies.

One of the most remarkable prickly fruits is that of the Calvary Clover. (Figs. 551, 552.) It is really a pod resembling those of pea and bean, but it is very long compared with its width. Sharp spikes are borne on both margins of the pod, and the latter is closely coiled into a spiral. The fruit is thus a prickly ball, since the spikes interlock and the pod is completely invested by them. When pulled apart the fruit resembles a crown of thorns.. (Fig. 552.) In connection with the dispersal of the above fruits, consider how the following animals may serve as agents:—

(1) Cows—by their tails.

(2) Horses—by their hairy fetlocks.

(3) Rabbits—by their fur.

(4) Human beings—by their clothing.

3. **Nuts.**—These are frequently invested with an additional prickly covering. Which purpose do you think is the more subserved by this:—(1) the scattering of the fruits by animals, or (2) the protection of the unripe fruits from the attacks of squirrels?

In the formation of nuts the plant at first sight seems to have exposed its fruit to a real danger in that the edible part of the nut is the nutrition stored up for the growth of the next generation. Doubtless many nuts are destroyed: one has only to examine a handful of beech or hornbeam nuts gathered beneath the parent tree to learn the truth of this. In a handful of about five hundred hornbeam nuts gathered from the ground in early December there were only fifteen containing seeds. All the remainder consisted of shells cleanly broken in halves with the seeds abstracted.

What creatures were responsible for all this destruction?

The writer once found several young oak trees growing on the decayed top of a hornbeam trunk. How can their situation be explained? Two explanations are offered: they may have been blown by the wind in an oblique direction from an oak near by, or they may have formed part of a squirrel's forgotten hoard. In this particular instance probably the former is nearer the truth, but nuts are frequently dispersed by the latter method. Interesting nuts to study are the tiny ones of alder and dock, and the much larger ones of hazel, oak, beech and chestnut. If living in the neighbourhood of these trees the student should study the gradual development of the various investments and the parts from which they have arisen.

4. **Berries.**—The scattering of nuts was seen to be largely accidental: there is nothing doubtful about the successful dispersal of berries, or more correctly, the seeds which they contain.

We know the havoc wrought by thrushes among the currants. Their depredations only pay tribute to the plant's successful devices in calling in their aid for the dispersal of its seeds. In berries there is the bright colour and sugary pulp to attract the birds, yet the plant ensures that its seeds shall be uninjured. Have you noted the smallness of the seeds in berries and the resistant nature of their seed coats?

These seeds are destined to travel the whole length of an animal's digestive system. Their small size enables them to escape injury in the mouth region, in addition they withstand the digestive processes by virtue of their hard seed coats. Birds are very efficient seed carriers. Think of their speed of wing and the distance some birds will have travelled before the seed has passed through their digestive system. Why should so many berries be red? Can you think of any other colour which would show up equally well against a green leafy background?

(Reference will be made to the bloom frequently found on berries in the next section on Stone Fruits.)

One berry, that of mistletoe, deserves special mention. Its pulp forms a very sticky mass. This is thought to be a contrivance expressly designed that birds, in endeavouring to get rid of the disagreeable mass, shall wipe the berry from their beaks upon the trunk of a tree. When we consider how the mistletoe lives as a parasite by sending roots into tree trunks to abstract the sap, we can understand how such an action by birds would place the berries in a favourable position for germination.

5. **Stone Fruits.**—These differ from berries in that the carpel ripens into three distinct regions, of which the innermost is very woody. The cherry (Figs. 439-442, 553) is a good example. The ovary lies as a green globular body within the cup-like flower stalk. The whole fruit is developed from the ovary alone. On the tip of a ripe cherry there is always a scar showing the position occupied by the style. The coloured skin, the juicy pulp, and the stone are all developed from the carpel. (The woody central region is absent in berries.) If we crack a cherry stone (*i.e.* the innermost part of the fruit wall or seed vessel) we find the kernel invested with a brown membranous skin. The kernel is a seed, the brown covering is the seed coat. The two halves into which the kernel so easily splits are the seed leaves. Other stone fruits of identical structure are the sloe, plum, damson, and peach. (Fig. 553.) A special characteristic of stone fruits is their firmness to the touch. A ripe plum becomes a flabby mass if its external skin be removed. There is the same tension here in the skin, and the same compression of the succulent cells that we found in the tissues of a soft elder stem. The sugar developed in the juicy part of a plum attracts much sap into the cells by osmosis, and the external skin of the fruit is put on the stretch.

The student should note the relatively late production of sugar in fruits. Has the previous harsh acid flavour any protective function?

The sap of fruits is especially liable to evaporation because of their exposed situations. We can explain the presence of "bloom" on fruits in this connection, for "bloom" is really a thin film of waxy material rendering the external skin water-tight, and so reducing evaporation to a minimum.

Will this bitter waxy skin protect the fruit at all? If so, from what insects?

Can you draw any parallel between the purpose subserved by the "bloom" and that performed by the multitudes of oil glands which give such a "pimpled" appearance to the skin of an orange berry? One further point demands notice in the structure of some fruits, viz., the size of the stone. In berries the hard parts are small, in stone fruits very large. In the former case we have already seen why such small seeds were produced; in the latter they are made large in order that animals may drop them from their mouths. Blackberry and raspberry are really collections of small stone fruits, although they are usually spoken of as berries. Each small black globe in a blackberry has in reality precisely the same structure as a plum or a cherry, the hard central part corresponding to the stone of a stone fruit, and like it, containing a seed. (Figs. 554-556.)

6. Fruits with Attractive Flower Stalks.—It will be well now to extend our previous definition of a fruit in order to include apples, pears, hips and strawberries.

In our hitherto rather limited definition we have regarded the fruit as the ripened ovary or carpels. We shall see presently that the four fruits mentioned above gain their succulent attractive nature by a great growth of the flower stalk. Since these are "fruits" in the popular sense of the word, we will enlarge our definition and say "The fruit is all that persists of the flower after ripening."

The apple flower and fruit are shown in Figs. 557, 558. We saw previously in cherry that the flower stalk grows up and forms a tube around the ovary, although it takes no part in the formation of the fruit.

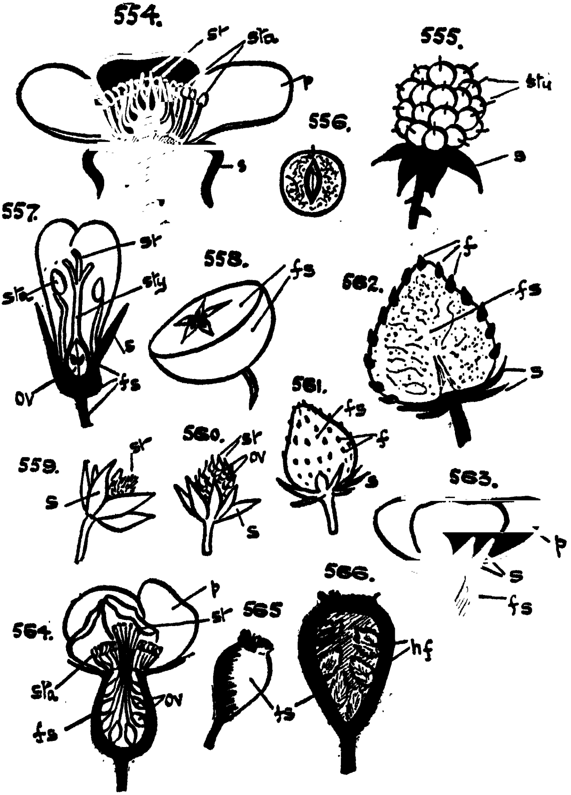
In apple it develops much further. In this flower there are five carpels radiating out from one another. In reality they are quite separate, but the flower stalk invests them and grows in between them so that they appear a green mass with the styles projecting above.

The great increase in size during the formation of the apple is due to the flower stalk growing and increasing in succulence. The five carpels may still be traced as a core of five cartilaginous chambers radiating from the centre of the cross section of the fruit and enclosing the pips (or seeds). Similar considerations apply to the pear flower and fruit. The succulence of a strawberry is obtained in a slightly different way. (Figs. 559-562.) The arrangement of the floral parts closely resembles that of a buttercup, the ovary consisting of numerous carpels quite free from one another. A close comparison of Figs. 554 and 562, showing longitudinal sections of flowers and fruit, makes clear that in the development of the latter the tiny nut-like carpels are widely separated by the greatly enlarged flower stalk which has grown up from the base of the flower.

What animal agent, excluding man, is most largely responsible for the scattering of strawberry seeds?

How do you account for the great difference in size between the fruits of wild and cultivated strawberries?

Many strawberry plants are quite barren. Is there any connection between this and the vegetative reproduction of the plant by means of its runners?



BLACKBERRY (*Figs. 554—556*).

Fig. 554.—Flower in L.S. The ovary is composed of many separate carpels.
Fig. 555.—Fruit Head composed of many small " Stone Fruits."
Fig. 556.—One Stone Fruit in L.S. (Compare with L.S. cherry, *Fig. 563.*)

APPLE (*Figs. 557, 558*).

Fig. 557.—Young Flower, Bud Stage in Longitudinal Section. Note that the flower stalk (*f.s.*) does not, as yet, completely enclose the carpels (*ov*). Ovules can be seen in the carpels.
Fig. 558.—Apple Fruit cut across. The flower stalk (*f.s.*) has developed to form all the juicy part. The carpels form the radiating horny core. The pips or seeds have been produced from the ovules seen in *Fig. 557.*

STAGES IN THE DEVELOPMENT OF THE STRAWBERRY (*Figs. 559—561*).

Fig. 554 will serve as a Longitudinal Section of the Strawberry Flower as well as for Blackberry.

The rose (Figs. 563-566) similarly ensures the dispersal of its seeds by rendering its flower stalk juicy and coloured. In this flower the flower stalk is a tube on the sides of which a number of separate carpels are produced. A style arises from the tip of each carpel and the stigmas lie in a bunch just beyond the mouth of the tube. The other organs of the flower (sepals, petals and stamens) are all borne on the margin of the cup. They can be traced in the rose fruit (the hip) as a withered black mass situated apically. Several hairy fruits (*i.e.* ripened carpels) are found within the scarlet flower stalk of the hip.

Do the hips fall off the rose trees?

How long can you trace them remaining on the plant?

Has the scarlet colour any connection with this, do you think?

A very plausible explanation has been adduced to account for the hairiness of the contained fruits.

Country children often torment each other by inserting these hairy fruits inside their clothing at the nape of the neck. The sensation thus produced is far from pleasant. The fruits are thought to irritate birds' tongues in similar fashion, and as a result they are rejected instead of being swallowed.

The haw or fruit of the hawthorn is like the hip in having the withered remnants of the other floral parts at the tip of the scarlet flower stalk, and also in remaining attached to the tree through the winter months.

Is there any truth in the popular saying, that a plentiful supply of rose and hawthorn fruits denotes a hard winter?

You should test the truth or falsity of this by observations carried on through several successive seasons.

7. **Dispersal by Water Agency.**—Almost any stream will show light grass and other "seeds" floating on its surface. But the most remarkable forms of distribution by water agency are those afforded by cocoanuts and water-lilies. The former have been found floating miles

---

Fig. 559.—The Petals have fallen. Note the many stigmas protruding from the sepals.

Fig. 560.—Later Stage. The flower stalk by its upward growth has brought the nut-like fruits more into view.

Fig. 561.—Well advanced stage. The flower stalk now is very large and has separated the tiny fruits.

Fig. 562.—Longitudinal Section through a ripe Strawberry.

WILD ROSE (*Figs. 563—566*).

Fig. 563.—Flower viewed from the side. (*f.s.*) Flower Stalk.

Fig. 564.—The same in section. N.B.—Many carpels (*ov.*) in the flower stalk.

Fig. 565.—The Scarlet Fruit or Hip.

Fig. 566.—The same in section showing hairy fruits (*h.f.*).

out at sea; in fact, the presence of cocoanut palms on the Pacific islets can only be explained by water carriage of the nuts.

Cocoanuts are specially fitted for this method of dispersal by their shiny waterproof coat and their thick fibrous air-containing region, which makes them buoyant.

In the white water-lilies the fruit sinks for ripening. This is the usual state of things in water plants, for they protect their developing fruits from water fowl in this way.

When ripe a slimy mass of seeds arises to the surface of the water. It does so because each seed is invested with a spongy air-containing coat. These spongy coats gradually become water-logged and the seeds sink, but this does not happen before they have travelled some distance from the parent.

In the yellow water-lilies the fruit breaks off from the plant and floats. The carpels are freed by the swelling and bursting of the outermost investing rind. Each carpel floats on the water because it is spongy and contains much air. Gradually this is expelled and the fruit sinks to the bottom of the pond. In some cases a floating carpel can be found whose seeds fall from it as it is floating on the water. This successive dropping of seed after seed is an ideal method for preventing competition between the seedlings for light and air.

SUMMARY.

DISPERSAL OF FRUITS AND SEEDS.

1. Dispersal by Animals.

(*a*) Prickly Fruits.—Small, inconspicuous, usually near the ground.

- (i.) *Geum.*—Hooked styles.
- (ii.) *Cleavers.*—Whole carpellary surface covered with hooks.
- (iii.) *Calvary Clover.*—Spiral pod, prickly along both margins.
- (iv.) *Burdock.*—Fruits contained in prickly investment.

(*b*) Nuts.—Accidentally scattered by animals—many destroyed.

(*c*) Berries.—Brightly coloured—ovary wall juicy except the outermost skin.

Small seeds with resistant seed coats in order to be uninjured by digestive juices.

Mistletoe.—Sticky nature aids attachment to tree trunks.

(*d*) STONE FRUITS.—Coloured—ovary wall in three regions—skinny, fleshy, woody. The bloom on stone fruit prevents evaporation of sap. The fruits are made firm by elastic skin pressing on turgid cells lying within. Harsh taste prevents fruit being taken before the seeds have ripened.

The large size of the stone ensures that it shall not be swallowed.

Blackberry and raspberry are really collections of small stone fruits.

(*e*) FRUITS WITH ATTRACTIVE FLOWER STALKS.—Definition of *Fruit*. The fruit is all that persists of the flower after fertilization.

(i.) *Apple and Pear*.—The core consists of the ripened carpels. All the pulp is a development of the flower stalk.

(ii.) *Rose*.—Scarlet flower stalk envelops the hairy fruit. Hairiness ensures ejection from the bird's mouth.

(iii.) *Strawberry*.—The ripened horny fruits are separated from each other by the greatly swollen flower stalk.

2. **Dispersal by Water.**

(i.) COCOANUTS travel miles by water.

(ii.) LIGHT SMALL SEEDS carried by river currents.

(iii.) WATER LILIES have spongy contrivances to enable their seeds to float.

PRACTICAL.

1. Trace the development of the hooks in Geum fruits.
Make a series of drawings of the ovary to illustrate this.

2. Collect as many prickly fruits as possible. In the following summer visit the places where they were found and examine the flowers. Sketch the ovaries.

3. Sketch all stages in the development of the investments of the hazel nut and acorn.

4. Gather a variety of wild berries and classify them according to their respective colours.
Make notes of the dates when they were (*a*) first and (*b*) last seen on the plants.

5. Calculate what percentage of a plum's weight consists of (*a*) attractive, (*b*) protective, (*c*) seed tissue.

6. Measure the circumference of a ripe plum as accurately as you can by means of a thread. Compare this with the length of a circular piece of skin removed from the plum.
Explain your results.

7. How many times is a cultivated apple (or damson) heavier than a crab apple (or sloe)?

8. Make a full list of plants from which you have gathered fruits covered with bloom.

CHAPTER XX.

The Plant and its Environment (I.).

1. **Introductory.**—The infinite variety of plant surroundings or environment goes far to explain the equally varied external appearance and internal structure of the plants themselves.

In order to live in any particular situation a plant must necessarily possess structural characteristics enabling it to obtain light, air and moisture satisfactorily under the conditions in which it is placed.

The characteristics so possessed may have been handed down to the plant from its remote ancestors, or from comparatively recent ancestors, or the plant itself may have produced them. Not that any *sudden* formation of an organ is meant here, nor that there is any *conscious* formation of an advantageous structure.

If we examine fifty plants of the same species we shall find that no two are exactly alike—they all present slight differences in structure: some stems slightly longer than others, some leaves longer or more deeply divided, some flowers with a slightly brighter colour or deeper tube, and so on. These differences, although so slight as to escape observation on a first examination, may have a far-reaching effect on the success of a plant and its progeny, for they help to fit the plant a little more perfectly for life in its particular environment. Further, there is a tendency for the plant to transmit similar characters to its offspring. These in their turn may develop the particular structural points to a slightly greater degree, and so their offspring may possess the beneficial characteristics in a still more pronounced degree.

The main facts to be remembered from the above are.

(*a*) That plant parts are variable.

(*b*) That the offspring tend to possess beneficial structures to a greater degree than the parents.

The student may ask: "Will all the offspring present these more pronounced characteristics?" Certainly not, but those in which they are lacking will be less fitted for their conditions of life, will be less successful, and in time will succumb under the stress of competition with their more fortunate rivals.

It is only by perfecting their suitability for growth in a particular district that plants can be successful. We have spoken above as though the only competitors against which plant has to struggle for light, air and moisture are the members of its own family. This is far from being the case. It may be largely so in a thickly sown cornfield, but not so under natural conditions, for hundreds of plants belonging to other families are all "striving their utmost" to gain a living, and perfecting themselves in the passive way mentioned above that they may do so.

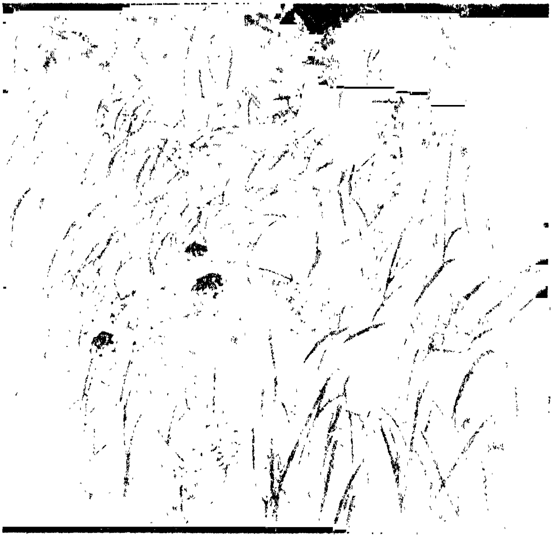


Plate II.—THE STRUGGLE FOR EXISTENCE BETWEEN GRASSES AND HEMLOCK.

This unconscious antagonism or competition between plants is particularly keen. It results in plants being stamped out of existence in a few generations if they do not possess variability sufficient to produce suitable structure. It explains the marked similarity in both the external and internal appearances of plants living under like conditions in the same regions. It is to be noted here that the reproductive organs are much less capable of adaptation to external surroundings than the vegetative organs; for instance, the majority of meadow plants will possess slender stems with narrow leaves, but their flowers will present a much greater variety. Floral structures have been passed down through long ages, their characters are practically fixed, and they are not subjected to the necessity of being in agreement with nutritive conditions. It is by their root, leaves and stems that plants must fit themselves for food manufacture under the conditions present. Since the leaf is so essentially a vital organ in this respect, it is a good thing for plant life that this particular part is extremely variable.

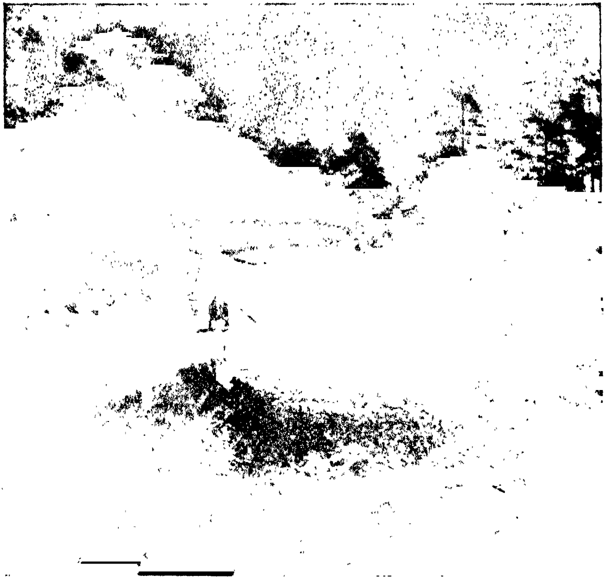


Plate II.—TRANSITION OF VEGETATION FROM UPLAND TO POOL.

No plant is *perfectly* fitted for life in its particular environment; but if it be successful in dominantly occupying one region against all competitors for many years its structure will gradually approximate in perfect suitability. But it may not occupy the same position for a great length of time. Imagine one kind of plant inhabiting a considerable area. Very frequently the stress of competition may cause annihilation of the plant in the central portion of the region occupied, and then those only on the fringe of the tract will survive. Thus it is that plants move their situations. A very good example is seen on the vegetation found in (*a*) a meadow sloping down to (*b*) the marshy sides of (*c*) a pond (see following chapter for details). We have in these three regions terrestrial, amphibious, and aquatic plants. If the plants growing in the water be examined they will show some characters typically found in land plants and yet, in addition, other points of structure rendering possible their life in a watery medium.

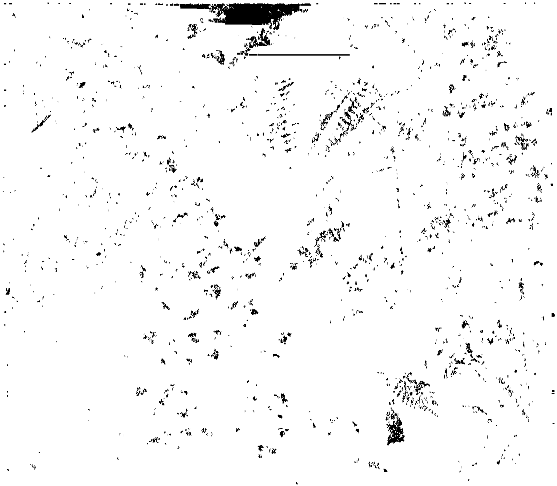


Plate IV.—A BROOKSIDE COMMUNITY.

The marsh plants will present characters intermediate between those inhabiting the land and the water.

These considerations make clear that the marsh plants are land plants which have been driven into the swamp by the more successful terrestrial forms. The water plants have gone further: unable to hold their own in the marsh they have elaborated their structure still more in order to render an aquatic mode of life possible for them.

This ceaseless struggle for light and air is silently going on all around us—on the roadside, in the hedgerow, on mountain, in valley, in pastures and in woods.

"What luxuriance! what a variety of vegetation!" we may exclaim on examining in detail the plant inhabitants of a meadow or a brook's side. If the plants could speak, they would say, "What overcrowding! What an endless struggle for the bare necessities of life!"

One of the most interesting studies is to take specimens of one particular plant found growing under different conditions, and to see how both its external form and internal structure present differences which can be explained by considerations of its varying habitats.

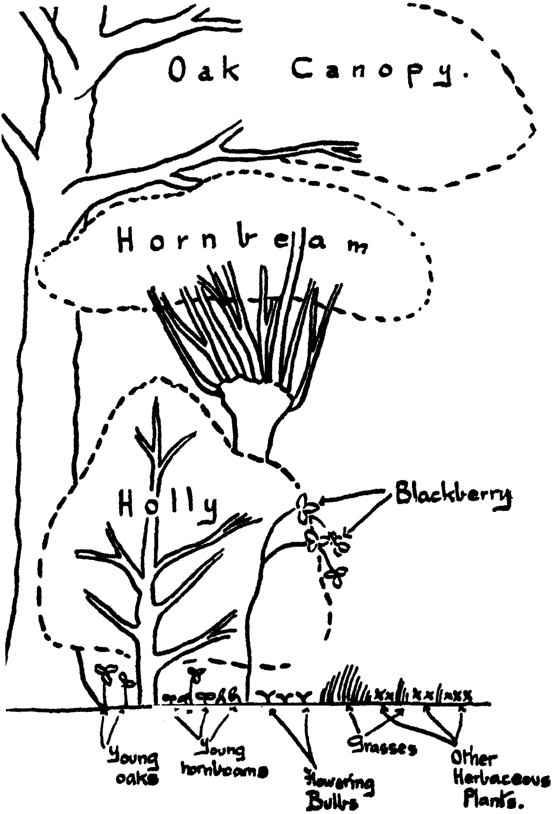
The above remarks must not lead the student to expect that he will find any very great difference between the vegetation of one year and the next in a particular spot. Occasionally violent changes will take place in a neighbourhood, as, for instance, when the trees of a wood are felled, or when marsh land is drained artificially, but usually it is only by observations carried on over many successive years that we can trace the introduction of some new plant, the silent extermination of another, and the gradual increase in numerical importance of one plant at the expense of another.

The plants of a particular neighbourhood form a "working arrangement" or "agreement" among themselves, but such agreement is only temporary. The factors which determine this delicate balance of life are so numerous and varied that sometimes even the most careful observer is at a loss to account for what he sees.

England is sadly behind in this particular branch of experimental work in Biology. Although splendid work has recently been accomplished, much remains to be done before we have the country's vegetation thoroughly investigated from the ecological point of view. (Plant ecology being that branch of Biology which investigates the intimate relation existing between plants and their environments.)

2. **Considerations of Light and Air.**—One of the factors producing the well-marked zones of vegetation which characterise tropical, temperate, and arctic countries is the duration and intensity of light. In the tropics vegetation is subjected to about equal alternating periods of darkness and intense light throughout the year. Contrast arctic regions with a "night" of several months' duration, followed by an equally long "day." Clearly, in the latter all vegetable life will

be at a standstill during the period of darkness Plants must here hurry forward their nutritive and reproductive processes whilst the light lasts. In our own country it is interesting to see how plants share the available light between them. In woodlands we find an upper canopy of leaf surface held out by the trees. These take the bulk of the light; they do so



567.

Fig. 567.—A Typical Woodland Society.

deservedly, because they have expended a vast amount of material in the production of woody branching stems.

The amount of light they absorb is closely connected with the disposition of their branches, and the size and shape of their leaves. The character of the undergrowth largely depends on the closeness or otherwise of this leaf canopy above.

A beech tree allows little light to filter through from above; an oak, which has a more open canopy, allows the passage of much more light, and consequently we find a variety of shrubs and herbs growing beneath its branches; a birch tree has a very open canopy, and allows very much light to fall on its more varied undergrowth.

A typical harmonious society was noticed by the writer a short time ago. It may be represented diagrammatically, as in Fig. 567. An oak formed the uppermost rather open screen of foliage; below this was a hornbeam tree of moderate size; below the hornbeam a holly shrub with a blackberry, whose straggling stems had succeeded in piercing the thick growth and spreading out their leaves just beyond the holly; immediately below the holly was a collection of young hornbeam plants a few months old, and oaks two years old; whilst towards the fringe of the ground shaded by the holly were bluebells and other bulbous plants, giving place on the outer side to grasses and other herbs.

Let us examine this association from the point of view of illumination. From the relative sizes attained by the hornbeam and the holly bush, neither oak nor hornbeam had stopped the passage of a large part of light. We note also that blackberry retains its leaves through a large part of the winter, and holly is quite evergreen, so these two plants would be able to avail themselves of the winter light falling between the bare oak and hornbeam stems. The paucity of herbaceous undergrowth is not surprising after what has been said above. An intense gloom is prevalent under holly bushes, for their leaves are thick and closely packed.

The young oaks and hornbeams had gained their start in life, thanks to nutrition stored in the seeds, but it is very improbable they will be living three or four years hence.

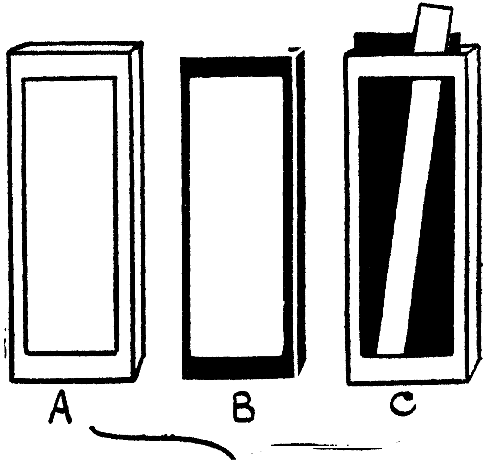
The bulbous plants make special provision for storage of nutriment, and their general habit fits them for life in shady positions.

At what date does the bluebell (*i.e.* wild hyacinth) put forth its leaves?

There remain but the grasses and their companions (buttercup, stitchwort, etc.) to be considered. The grasses encroached most into the shaded region, but not far; the other herbs stopped short as soon as the shade was appreciable.

How can the relative illumination be determined with any degree of exactness? We have used the following simple contrivance for the purpose, and it answers remarkably well. A glass microscope slide is fitted into a paper cover, in which an oblong window is cut. (*A*, Fig. 568.) A brown tinted paper is slipped in between the glass and the *back* part of the cover, so that its tint can be seen through the glass (*B*).

A strip of photographic sensitive paper is next inserted immediately behind the glass and tinted slip. Its white colour shows strongly against the brown tinted paper (*C*).. The apparatus is then exposed to the full sunlight, and the time taken by the sensitive strip to become the same colour as the brown is carefully noted in seconds. This serves as an index of the intensity of full sunlight.



568.

Fig. 568.—Apparatus for determining the intensity of Illumination. For explanation see Text.

The sensitive paper is then replaced by new, and the instrument is placed on the ground beneath a tree. The paper requires a considerably longer time to assume the brown tint. By comparison of the times required in the open and under the tree, we can find what percentage of the light has been absorbed by the latter.

Simultaneous exposures in different parts of the region being investigated, enable us to map out the light and shade areas in detail.

The following are a few results so obtained:—

(1)

(*a*) In the open. Time required, ¼ minute.
(*b*) Under young larches, with branches 15 feet from ground. 1 minute.
(*c*) Under closely planted oaks, with trunks 1½ feet diameter and 3 yards apart from each other; branches 12 to 20 feet from ground. 1¼ minutes.
(*d*) Under birch. 4 minutes.
(*e*) Under gorse (open specimen). 6 minutes.
(*f*) Under blackberry. 10 minutes.
(*g*) Under oak, hawthorn, and blackberry. 20 minutes.

(2)

(*a*) In the open. Time required, 1 minute.
(*b*) Under a gorse bush. 10 minutes.
(*c*) Under an oak tree. 1½ minutes.
(*d*) Under a holly bush. 30 minutes.

(3)

	Time required.	Amount of Light absorbed.
(*a*) In open—fully exposed ...	¼ min.	—
(*b*) Under birches (with trunks 1 ft. diam.)	1¼ min.	·8
(*c*) Under hornbeams (seven trees in a circle of 40 ft. diam.) ...	1¾ min.	·86
(*d*) Under oak (trunk 3 ft. diam., branches 7 ft. from ground)	3 min.	·92
(*e*) Under blackberry (growing in open, with leaves lying but 3 in. from ground)	2¾ min.	·91
(*f*) Under a holly bush	7 min.	·96
(*g*) Under hornbeam, holly, and blackberry (plants being 12 ft., 1 ft., and 3 ft. respectively from the ground ...	20 min.	·99

How Plants Share the Available Light.—Fig. 567 shows us that in a woodland district shrubs avail themselves of the light unused by trees, and that herbs utilise some of the light which has escaped the absorbent action of both trees and shrubs. It is particularly instructive to note how the wild climbing plants place their leaves on an equality with those of shrubs and even trees.

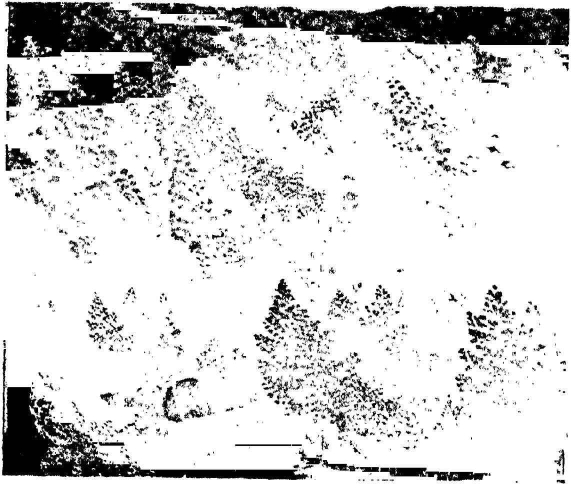


Plate V.—The Leaf Mosaic of Maiden Hair Fern.

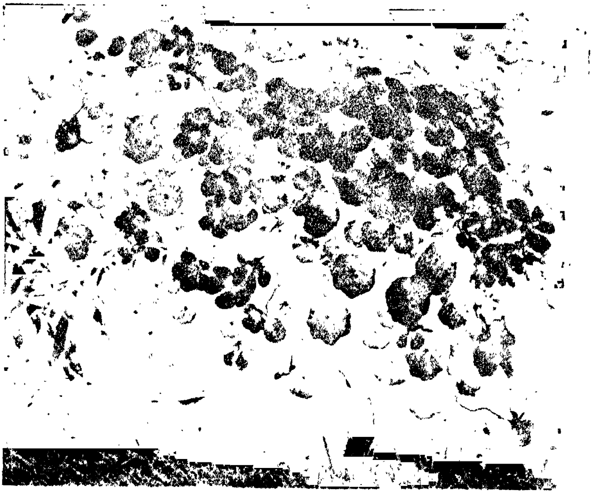


Plate VI.—The Leaf Mosaic of Garden Nasturtium.

Their stems are long and slender, being much too weak to maintain an upright position by their own strength, yet by modification of different parts into climbing organs they are able to hold out their leaves to the light. Ivy climbs up walls and tree trunks by the aid of roots, which emerge from the stem and hold it firmly to the support by seeking out all the dark crevices. Clematis completely surmounts a hedge by twisting its sensitive leaf stalks round the stems of the bushes. The hooked prickles on blackberry stems, leaf stalks, and leaf veins prevent the plant falling back once it has forced its way through a shrub. Similarly, the goose grass or cleavers holds itself upright, and grows straight through a thick hedge. The honeysuckle, bryony, hop, and large white convolvulus are able to grow through and emerge from the top of a hedge or bush by means of their twining stems. The small convolvulus similarly twines in a spiral up the upright stalks of wheat or other corn crops. How little light it would receive if its slender stems remained flat on the ground!

NOTE.—In connection with this chapter the student should revise the branching of stems and the formation of leaf mosaics. (See Chapter xiii., Figs. 294-300.)

SUMMARY.

THE PLANT AND ITS ENVIRONMENT (I.).

Plants are fitted by their structure to live in the position in which they are found.

The structure may be acquired or inherited from past or recent ancestors.

Plants not possessing the required structure perish.

Plants fit themselves for their environments by modifying their variable parts.

Leaves and stems are the most variable parts.

Competition between plants for light, air and moisture is very keen—"the weakest goes to the wall."

Plants may be driven by competition to seek different homes and to live under different conditions.

They can only do so by adapting themselves to their new habitats.

Light and Air.

Duration and intensity of light have much to do with the formation of zones of vegetation.

In English woods, trees, shrubs and herbs share the light with one another.

Climbers reach the light by developing sensitive climbing roots, stems or leaf stalks.

The intensity of light under various trees, etc., can be ascertained by the use of photographic printing-off paper, and estimations can be made to determine the percentage of incident light absorbed by the leaves of any particular plant.

PRACTICAL.

1. Make comparisons of the intensity of the light underneath oak, beech, birch and elm trees.
2. Study a hedgerow formation from the point of view of illumination. Draw a sectional view showing the direction of the light and the amount each plant receives.
3. Make a collection of leaf mosaics.
4. Make lists of the undergrowths found beneath different forest trees, correlate these with the thickness of the leaf canopy and the height of the *lowest* branches from the soil.
5. Take a walk through a woodland region in winter, and make notes on the positions of all evergreens you find.
6. Contrast the intensity of light under a leafy tree and under the same in a leafless condition.
7. Study the habits of wild climbers *in situ.*
8. Try to pull a blackberry stem backward through the bush it has surmounted.

* * *

CHAPTER XXI.

The Plant and its Environment (II.).

1. **Moisture.**—This is as important to plant life as is the air. In previous chapters we have learnt how the air supplies oxygen for breathing and carbonic acid gas for food-making purposes. Water is also necessary for food production, since water and carbon dioxide are essential in the synthesis of sugar. Further, it is vitally necessary in order that the protoplasm may live. It is also the vehicle for transmission of soluble raw food materials and elaborated foods. The chief factors influencing the amount of water available are the rainfall, wind, contour of the land surface, character of the soil, and local geological formation.

2. **Its Conditions.**

(*a*) AMOUNT OF RAINFALL.—Not only the amount of rainfall during a year, but also the seasons of the year at which the rain falls must be taken into account. For instance, in the tropics a period of torrential rain is followed by a dry season lasting many months. Plants inhabiting these regions must make provision for this. They must be able to endure this alternate soaking and dessication without injury. They frequently shed their leaves during the dry season, but utilize this particular time of the year for their flower and seed production.

In other parts of the tropics there are vast deserts where the only plant inhabitants are those which can reduce to a minimum the amount of water they give off (See under "Xerophytes," page 248).

In temperate regions more equable conditions occur, there is not the alternate soaking and parching of the soil as in the tropics, and consequently we find plants of different structure.

(b) WIND.—The wind promotes transpiration from leaf surfaces, and also exercises a drying action on the soil. Other things being equal, plants exposed to winds must

Plate VII.—TROPICAL VEGETATION, JAVA.

economise their water expenditure by various means. Of course it greatly depends on the character of the region the wind has traversed previously whether it will exercise a drying action or not. Notable instances are the east and south-west winds of our own country and the north-east and south-west monsoons of India.

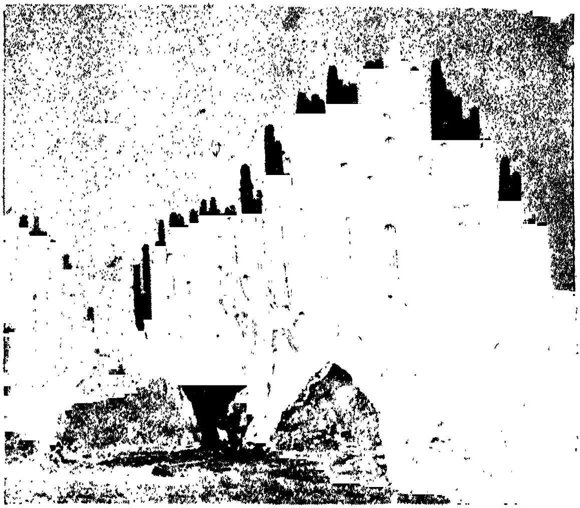
(c) CONTOUR OF THE LAND.—Slopes largely affect the drainage of a region. This applies not only to the slope of the surface soil, but to that of the impervious rock lying below. Swamps are nearly always level ground where the water cannot run off. On mountain sides we usually find plants reducing the amount of water they give off. We shall find a little later that the coldness of the soil is another influence preventing plants from having a sufficient water supply.

(d) THE SOIL.—The vegetation of a limestone or chalky region differs markedly from that inhabiting a clayey soil, whilst a bare granite rock will be devoid of plant life except for a few crusty lichens.

All soils differ widely in their inherent fertility, which is determined by the many and various causes discussed in Chapters xxiv. and xxv. of this book. The porosity of a soil is a most important factor in determining what plants shall grow there, for porosity modifies the water supply, and no plant can live in a dry soil if it does not reduce its water expenditure in some way or other. Again the geological composition of the subsoil determines to a great degree what mineral substances will be available for root absorption. If a young seedling be watered with salt solution it soon becomes flaccid. This is the result of the osmotic action of the salt in withdrawing the watery sap from the soft cells of the roots. Thus a plant cannot live in a salty soil unless it reduces its water expenditure considerably.

Another factor influencing the amount of water held by the soil is the amount of humus or decaying organic matter present. This humus is mainly formed from fallen leaves, and the amount present in various soils is largely dependent on the rate at which the leaves decay. Some leaves, as those of pine and beech, decay slowly, whilst those of oak and elm do so more rapidly. The more humus that is present in a soil the more water will it retain. The relatively small amount of humus in the soil under pines and beeches partly accounts for the scantiness of the undergrowth beneath these trees. It will be seen later that the humus constituents of a soil supply important minerals, especially nitrates necessary for plant growth. Gardeners make use of this fact when they use leaf mould for potting purposes. They also use it for its lightening effect on the soil.

3. **Classification of Plants with Respect to the Amount of Water Available.**—In thinking of the amount



Plates VIII. and IX.—A CONTRAST IN ENVIRONMENTS.

of water available for a plant we must not imagine that this is identical with the amount actually present in the soil. The roots may be prevented from absorbing the soil water by the coldness of the soil or by the presence of salt or organic acids in it. In this section "available water" means the water which the plant is actually able to absorb.

We may divide all green plants into three groups (Xerophytes, Mesophytes, Hydrophytes), according as their available water supply is too little, sufficient or more than sufficient. The majority of our common plants belong to the middle group. Their mesophytic structure mainly consists of a good root development, comparatively much woody water-conducting tissue, and large flat thin leaves plentifully supplied with veins and stomata.

Xerophytes, on the one hand, and hydrophytes, on the other, present two extremes: the former are compelled to husband their scanty water supply: the latter grow either in permanently wet soil or more or less submerged in water. Since xerophytes and water plants constitute groups of plants living under totally diverse conditions, we will examine their structures in some detail that we may interpret them in the light of their correlation with, or adaptation to environment.

4. **Xerophytes.**—In dealing with this biological group of plants, our main guiding principle is that transpiration must be reduced. No plant can live unless its cells have the required amount of cell sap, and if the water is being given off at a greater rate than that at which it is being absorbed, dessication and death must sooner or later result. Such plants, however, are "in a quandary" since the leaves are the transpiring organs, and if these be reduced in number or size the plant is less well supplied with elaborated food, for we have already investigated the leaf's functions and know that photosynthesis is its main work. The problems to be "solved" by the plant are briefly these:—

(i.) Transpiration must be reduced;

(ii.) Food elaboration must not be reduced;

(iii.) How can the "happy mean" be struck between these?

Bearing the above in mind, we will now examine the group in detail.

5. **The Various Habitats of Xerophytes.**—

(*a*) In deserts, where the soil is permanently dry, we should expect pronounced xerophytic characters.

(*b*) On mountains the coldness, poorness, and shallow depth of the soil render little water available.

(*c*) The extreme coldness of the soil and wind in arctic regions acts similarly.

(*d*) In the tropics transpiration must be reduced during the long dry season.

(*e*) There is a poor and precarious water supply for plants.

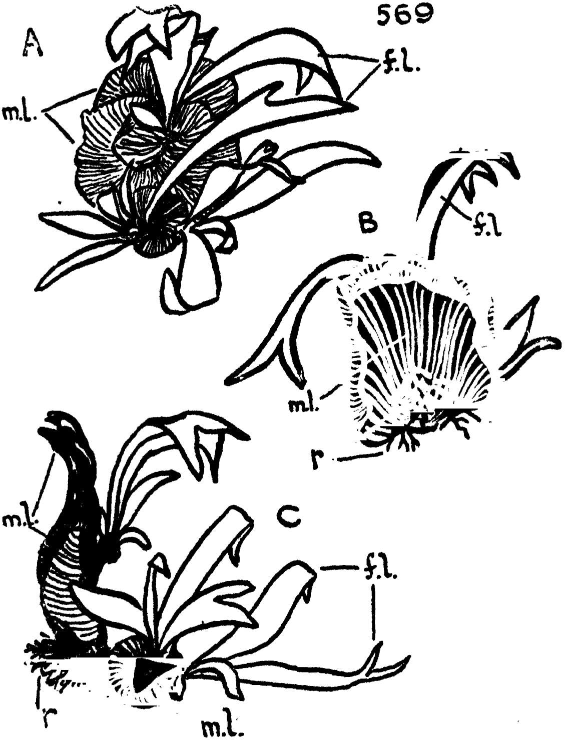


Fig. 569.—*Staghorn Fern. Viewed from* (A) *the front*, (B) *the back*, (C) *the side.* A large Australian Fern which perches on tree trunks. It has two kinds of leaves: (i.) (*f.l.*) Foliage Leaves, which are green in colour and frequently of a horned shape. (ii.) (*m.l.*) Mantle Leaves, which are broad, flat, shield-shaped leaves, brown in colour and standing erect, almost parallel to the tree trunk on which the plant is perched. Its Roots (*r.*) are a fibrous mass, which ramifies in the dust and moisture collected in the niche between the mantle leaves and the tree trunk. These roots spring from the *back* of the mantle leaves.

growing perched on the trunks of trees. (Fig. 569.) In England the best examples are mosses and small ferns. The trunks of trees shading the rivers in South Scotland are almost covered with perching ferns. We

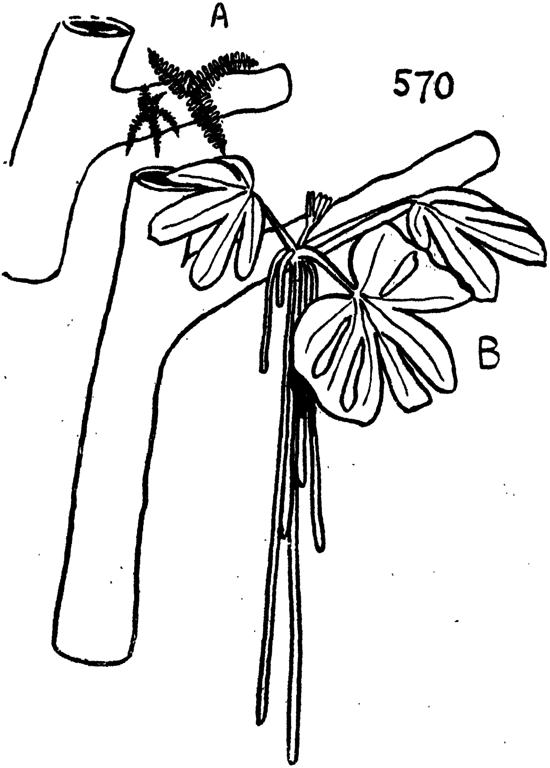


Fig. 570. (A) *Small British Epiphytic (or Perching) Ferns.* (B) *Large Tropical Perching Plant (an Aroid).* Note its aerial roots hanging down into the air.

find the greatest variety of perching plants (epiphytes) in tropical forests. There is little undergrowth in such a forest, the intense gloom consequent on the thick leafy canopy above, renders such vegetation impossible.

The bulk of the smaller plants are perched upon (*i.e.* not organically connected with) the larger trunks and branches. Orchids and aroids are mostly of this type of growth. Some start as climbers, die away in their lower regions, and slowly ascend the tree. Others have sprung from exceedingly small seeds which, blown by the wind into the chinks of the bark, have germinated so quickly that they have gained a foothold by means of their clasping roots before they could be dislodged. A special feature of these epiphytes is that they frequently send forth roots which hang down into the air. Some of these may reach the soil and by branching there may absorb water and mineral substances in the normal way. Others never reach the ground, they hang as long vertical ropes, absorbing moisture from the saturated atmosphere and also making food by their internal green tissues. (Figs. 570, 571.) The leaves of these plants are frequently small or absent altogether. The student should study how epiphytes have solved the problem stated at the end of the preceding section.

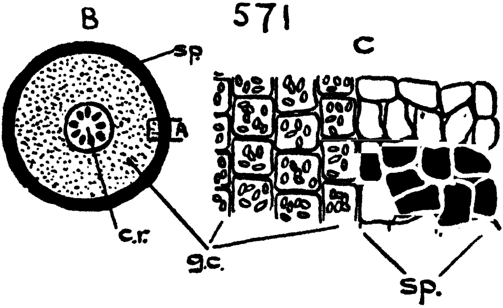
(*f*) Mosses upon walls and the familiar house-leek upon house roofs are very badly situated for water. Their position is similar to that of epiphytes.

(*g*) Plants by the sea shore or in salt marshes have their roots surrounded by water, yet are much in the position of the "Ancient Mariner." The salt in the water precludes much of the latter from being used.

(*h*) Plants growing just back from the shore on the sand dunes are in a very awkward position; not only is the soil very dry for a considerable depth, but in its deeper regions the water which is found is very salty; add to this that the plants are exposed to the full blaze of the sun, the full force of the wind, and are repeatedly being completely covered by new drifts of sand. Evidently in these shifting regions the plants to thrive best will be those possessing xerophytic characters, together with the powers of producing very long branching roots and of renewing their growth in the event of their being completely covered. Long coarse grasses are usually the first plants to thrive in these unsatisfactory regions. When by their binding action they have formed the dunes, they are followed by the sea-thorn, heather, etc.

6. Xerophytic Characters. (Figs. 572-579.)—The following are the main points of xerophytic structure. It must not be expected that they will or can all be exhibited by one plant; in fact, some of the characteristics are mutually prohibitive. Most xerophytes, however, will exhibit more than one of the structural peculiarities described below.

571



572

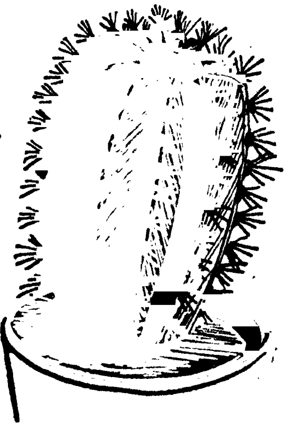
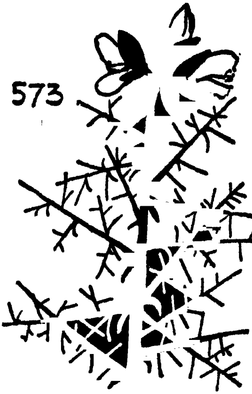


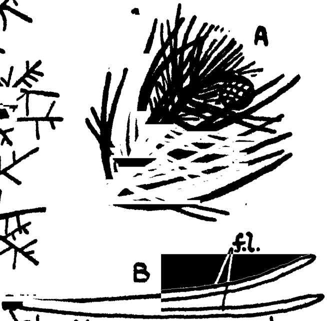
Fig. 571.—(B) *Cross section of the Aerial Root of an Orchid*; (C) *Magnified view of the region marked* (A). (*sp.*) Outer Spongy Absorbent Part; (*g.c.*) Cortex containing Chloroplastids; (*c.r.*) Central Conducting System.
Fig. 572.—*A small Cactus.* Note the swollen ribbe stem (a water reservoir), the absence of leaves, and the protective armour of spines.

(*a*) SUCCULENCE.—The plants store up water in themselves. This is well seen in swollen cacti and euphorbia stems and in stonecrop leaves. (Fig. 572.)

573



575



574

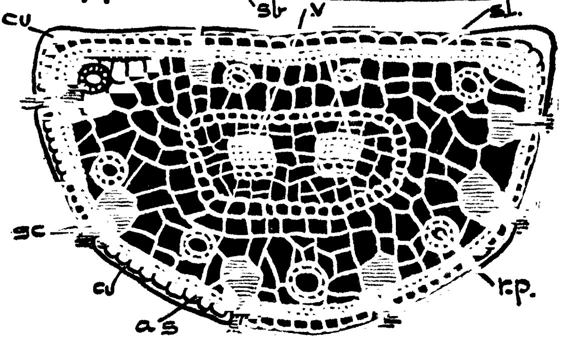


Fig. 573.—Furze, Flowering Twig. Note how all branches and leaves are sharp thorny structures. The green colour of the stems makes up for the very small size of the leaves.

PINE (*Figs. 574, 575*).

Fig. 574.—Cross Section of a Pine Leaf. The solid character of the leaf is well shown. The following are most noteworthy points of structure:—

(*a.*) Thick cuticle (*cu.*).
(*b.*) Sunk Guard Cells (marked black in the figure *g.c.*)
(*c.*) Strengthening thick-walled layer just below the outer skin (*s.l.*).
(*d.*) Very small air spaces (shaded in the figure) (*a.s.*).
(*e.*) Only two veins (*v.*).
(*f.*) Eight resin passages or ducts (*r.p.*).

Fig. 575A.—End of a Branch bearing a young Female Cone. Note the long needle-like foliage leaves.

Fig. 575B.—A pair of Foliage Leaves (f.l.) *borne on a short Branch or Spur* (sb.).

(*b*) THICK LEATHERY CUTICLE.—This hinders transpiration. Cacti have leathery stems, holly and aloe leathery leaves.

(*c*) WAXY COVERING.—Further hindering transpiration. The bloom seen in those plants mentioned in (*a*) consists of a thin film of wax secreted by the outermost parts. The bluish tinge of a pine leaf has a similar origin.

(*d*) THICK SAP.—Generally characteristic of desert plants. Such a sap evaporates less quickly than a more liquid one.

(*e*) THORNS.—Due to dryness. Necessary in the case of desert plants, where they are the only vegetation for miles, and would otherwise be eaten or destroyed by animals. This will be seen in cacti and euphorbias. Among English plants holly and furze are good examples. (Fig. 573.)

(*f*) HAIRY LEAVES.—A common characteristic of mountain plants and those on the South African veldt. The object is to reduce transpiration by protecting the stomata from the wind. Lady's mantle affords a good English example; its hairiness varies according to situation.

(*g*) SUNKEN STOMATA.—Same object as *f*. The leaves of pine and other conifers show the stomata sunk in pits. The air in these pits tends to remain saturated with moisture. (Fig. 574.)

(*h*) FEW STOMATA.—Shown in most xerophytic leaves. The fewer the stomata the less transpiration, since there are fewer exits for the water vapour.

(*i*) SMALL AIR SPACES IN THE LEAF.—Therefore less area of moist cell surface is exposed to evaporation within the leaf. Pine leaf shows this well.

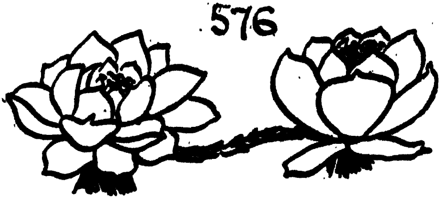
(*j*) FEW VEINS TO THE LEAF.—Correlated with the small water supply. Many leathery leaves of conifers show but one vein.

(*k*) CLOSE PACKING OF LEAVES.—Leaves thus kept away from wind and from the sun's heat. Examples: Mosses, house leeks. (Fig. 576.)

(*l*) ROSETTES.—The result of leaf-packing (*k*), coupled with shortness of stem growth; subserves the same functions as (*k*). The crassulas furnish good examples.

(*m*) STUNTED HABIT.—A most marked feature of arctic and mountain floras. Plants growing upon exposed moors show the same phenomenon. Transpiration is lessened by the plants evading the wind. In arctic plants it has been thought to be partly produced by the stunting action of the light during the long "day." The student should compare the willows and the bedstraws that he finds growing in (i.) sheltered lowlands, (ii.) exposed upland surfaces.

(n) EVERGREEN NATURE.—So that, during the bright days of winter, the plants may make up for their diminished food-making capability. Examples: Pine, spruce, yew, holly.



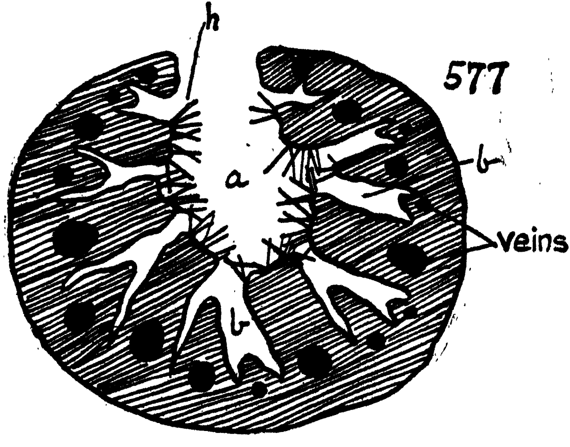
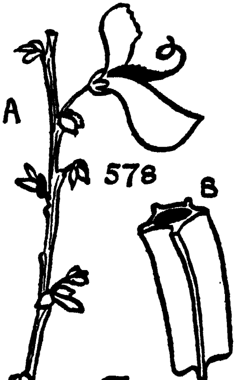


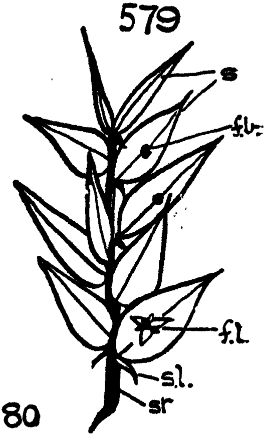
Fig. 576.—House Leek. A plant exposed to strong winds and full sunlight, yet having a poor water supply. N.B.—The swollen, closely-overlapping leaves.

Fig. 577.—Psamma Grass.—Cross section of a backward-coiled leaf, showing how the backward curling of the leaf keeps the stomata from the wind. Hairs (*h.*) prevent water vapour escaping from the spaces (*b.*) into the space (*a.*).

(o) THICK LEAVES.—Less transpiration from such leaves than there would be if they were thinner and more spread out.

(p) DEEP-SEATED ROOTS.—Where the soil is sandy and dry.





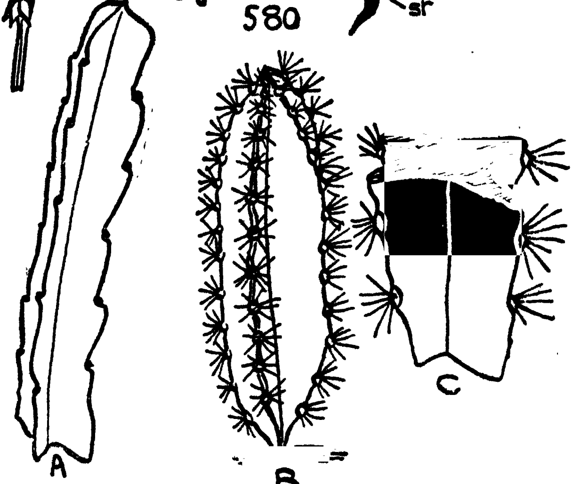


Fig. 578.—Broom. A. *Flowering Twig;* B. *Stem Enlarged.* Correlate the small leaves with the grooved or winged stem.

Fig. 579.—Butcher's Broom.—(*st.*) Ordinary Stem; (*s.*) Leaf-like Stems; (*s.l.*) Scale Leaf, in the angle of which a Leaf-like Stem arises; (*f.b.*) Flower Bud; (*f.l.*) Open Flower.

Fig. 580.—Cacti. A. *A green leafless Cactus Stem with three Projecting wings.*

B. *Another specimen with four Projecting Wings.* All the branches and leaves are converted into thorny structures.

C. *Lower part of the same,* to show the flanging of the stem more clearly

Pine has roots running parallel to and not far below the surface of the ground. Its natural home on the mountain's side possesses only a shallow soil resting on the hard rock. Contrast this with the plants forming, and growing upon, sand dunes.

(*q*) **BACKWARD COILING LEAVES.**—Coiled leaves form a chamber into which the stomata open. The air in this chamber speedily becomes saturated with moisture. This is very well seen in the heathers and in shore grasses. (Fig. 577.)

(*r*) **SMALL LEAVES.**—Frequently needle-like. Examples: Pine, yew, broom, furze. Leaves merely scales in butcher's broom.

(*s*) **ABSENCE OF LEAVES.**—Many cacti merely consist of a swollen leafless stem above ground and a root below. (Plate viii., page 247.)

(*t*) **GREEN STEMS.**—This is a direct consequence of leaf reduction, nearly always seen in plants possessing few, small, or no leaves. Food-making area must be supplied (broom, furze, cacti). (Fig. 578.)

(*u*) **GROOVED STEMS.**—The stomata are placed at the bottom of the groove, away from the wind. (Fig. 580.)

(*v*) **WINGED STEMS.**—To increase the food-making surface.

(*w*) **STEMS AND LEAF-STALKS LOOKING LIKE LEAVES.**—As in butcher's broom and acacia. The advantage here is that the *edge*, instead of the flat leaf surface, is placed to the *heat*. (Fig. 579.)

(*x*) **SLOW GROWTH AND LONG LIFE.**—Consequent on slow processes of nutrition.

SUMMARY.

THE PLANT AND ITS ENVIRONMENT (II.).

1. Moisture is necessary:
   (*a*) For sugar production.
   (*b*) To keep the protoplasm in a saturated condition.
   (*c*) To transport foods and food materials.
2. Conditions regulating the amount of moisture in the soil:
   (*a*) Rainfall.
   (*b*) Wind.
   (*c*) Slope of land.
   (*d*) Rock constituents of the soil.
   (*e*) Amount of humus or decaying organic matter.

3. Classification of plants according to their water supply:
   - (*a*) Xerophytes have insufficient water supply.
   - (*b*) Mesophytes have sufficient water supply.
   - (*c*) Hydrophytes have excessive water supply.
4. The problem confronting xerophytes:
   The reduction of transpiratory, without a corresponding reduction of assimilatory, surface.
5. Xerophytic situations:
   - (*a*) Deserts.
   - (*b*) *Mountainous regions.*
   - (*c*) Arctic regions.
   - (*d*) Tropical regions.
   - (*e*) Epiphytic situations.
   - (*f*) *Walls and house roofs.*
   - (*g*) Seashores and salt marshes.
   - (*h*) Sand dunes.
6. Xerophytic characters:
   - (*a*) Succulence.
   - (*b*) Leathery cuticle.
   - (*c*) Waxy surface.
   - (*d*) *Viscid sap.*
   - (*e*) Thorny nature.
   - (*f*) Hairy leaves.
   - (*g*) Sunk stomata.
   - (*h*) Few stomata.
   - (*i*) Small air spaces.
   - (*j*) Few leaf veins.
   - (*k*) Close-packed leaves.
   - (*l*) Rosettes of leaves.
   - (*m*) Stunted growth.
   - (*n*) Evergreens.
   - (*o*) Thick leaves.
   - (*p*) Deep roots.
   - (*q*) Leaves rolled back.
   - (*r*) Small leaves.
   - (*s*) Absence of leaves.
   - (*t*) Green stems.
   - (*u*) Grooved stems.
   - (*v*) Winged stems.
   - (*w*) Leaf-like stems.
   - (*x*) Slow growth and long life.

PRACTICAL.

1. Keep a record of the rainfall where you live.
2. Examine the moisture of the soil in any selected region with a view to tracing its dependence on the slope of the land, the nature of the soil, and the amount of humus present.
3. Study the geological formation of your own district.
4. Investigate the depth of humus found under a number of forest trees. Correlate with amount of moisture, extent of undergrowth, and intensity of illumination.
5. Study xerophytes *in situ*. Tabulate their xerophytic characters and the physical conditions under which they live.
6. If possible study the flora of a strange district during your vacations. Carefully note all deviations from your list of "home" plants.
7. Ask friends living in different parts of the country to co-operate with you by exchanging plant specimens, lists of plants found, and details of environment

CHAPTER XXII.

The Plant and its Environment (III.).

1. **Water Plants.**—The most important fact in interpreting the structure of water plants is that carbonic acid gas is readily soluble in water, but oxygen is only slightly so. Since decaying organic matter is always present in exposed ponds or streams and carbonic acid gas is a product of such decomposition, it follows that a large amount of this gas will be present in natural waters. Plants growing in submerged positions will thus be enveloped in a solution of the gas which they require for food formation. To this should be added that the necessary mineral salts are also present, dissolved in the water. Aquatic plants, therefore, are very well supplied with all the raw materials—water, carbonic acid gas, and minerals—from which food is made.

As a result we find that rapid growth and much branching are characteristic of the whole group. (Fig. 581.) This subserves vegetative reproduction, for many of the branches are broken off by currents and float away to form new plants. It is a general axiom among gardeners that if a plant produces many stems and leaves it will produce few flowers; the biological significance of pruning trees to promote flower and fruit formation depends on this fact. Water plants, as we have seen above, are rapid growers; they reproduce themselves readily by means of their detached branches, and so there is not the necessity for them to produce flowers. A very good instance of this is the way in which Elodea, the Canadian Waterweed, has gradually spread through our rivers and ponds without producing flowers.

Another cause tending to prevent the production of flowers by aquatic plants is the difficulty attending their pollination. Insects are relatively few and there is great danger of the pollen becoming wet and so unfit for dispersal.

Where flowers are produced they are generally specially adapted for pollination by water agency. In some of these plants the male flowers break off and float away until they come in contact with the female flowers. Sometimes the female flowers lie submerged but are provided with long styles so that the stigmas may be at the water surface in order to receive the floating pollen. In one particular plant (Zostera) the pollen grains have the same specific gravity as water. They thus tend neither to rise nor fall in the water and are carried passively by the currents to the female flowers which are borne at various depths in the water. We have already dealt with the submerged seed-ripening found in this group in an earlier chapter.

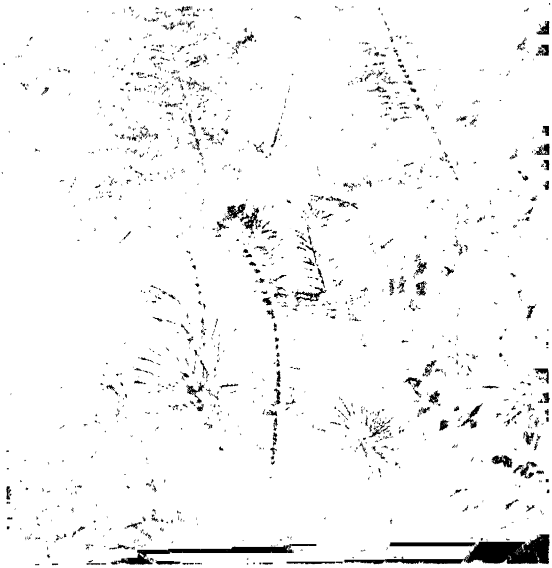
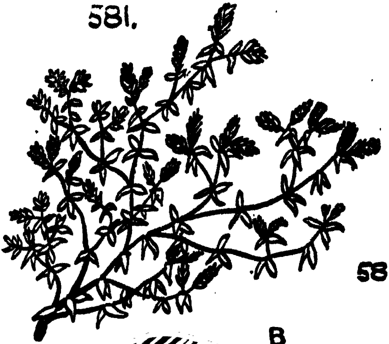


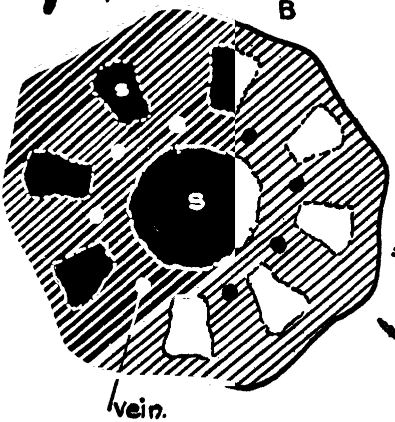
Plate X.—A MARSHLAND COMMUNITY—HORSETAILS.

Although well provided with raw food materials, they are badly supplied with the oxygen they require for respiration. In Xerophytes there are water reservoirs; in water plants (Hydrophytes) there are air reservoirs. These latter are large spaces in the stems and leaves. (Figs. 585, 587.) The stems are frequently hollow (Fig. 582), and all the spaces communicate with each other so that oxygen may reach every cell of the plant. Marsh plants show these air spaces also. They are liable to be submerged in times of flood and must make provision accordingly. (Fig. 584.)

581.



582



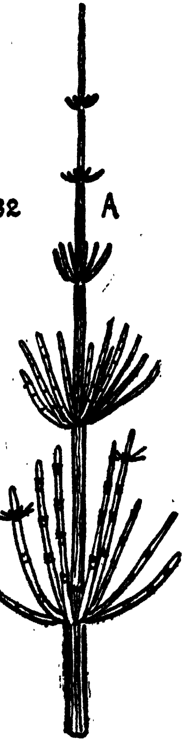
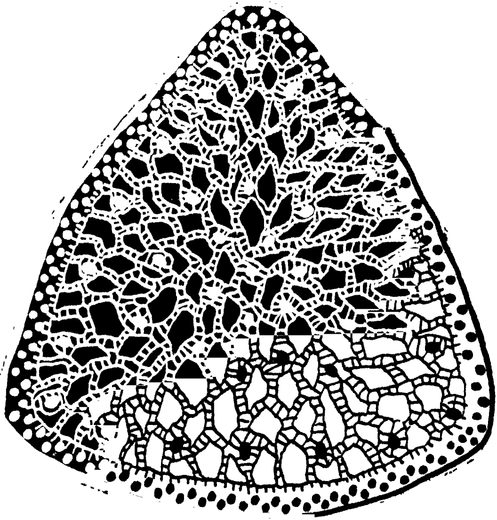
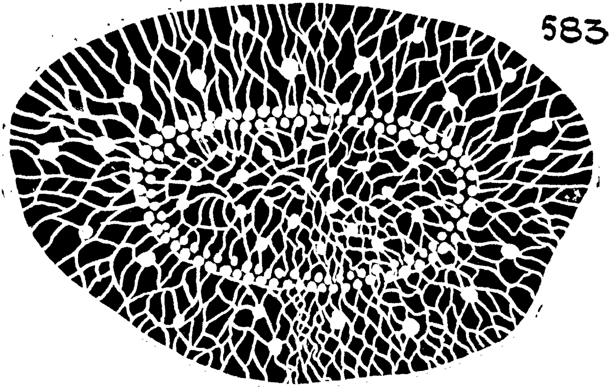


Fig 581.—Elodea (the American Waterweed). A much tufted branched plant in habit, growing in almost every British pond.

Fig. 582.—The Horsetail. (A) *General view of the upper part of the Plant.* (B) *Transverse Section of the Stem.* Note the large air spaces (*s. s.*), and (in Plate X.) their social habit.



585



583

Fig. 585.—The Sedge. Transverse Section of Stem. The veins are shown as dots. The air reservoir system is very well developed.

Fig. 583.—The Sweet Flag. Transverse Section of Stem. The network shown is precisely the same as that in *Fig. 585.* This stem is embedded in the mud at the side of water.

These large air chambers subserve another important function: they act as "floats" by giving additional buoyancy to the leaves and enabling them to lie as near the light as the length of the stem permits. In terrestrial plants the roots absorb, the stems conduct, whilst the leaves give off, water. There is a definite upward transpiration current. The path of the water is well marked and there is provision made by cuticle, cork, and bark that its escape shall only be by way of the stomata.

In submerged water plants the *whole surface* of the plant absorbs the water and mineral substances, there is no upward current of "sap" in the plant, and free access or escape of the water is allowed from any part.

The roots are merely attachment organs and are consequently little developed. In free-floating forms the roots may be entirely absent, but usually they are developed as bunches of thin white threads from various points of the stems and are absorptive in function. The student will have noticed the white stringy roots of watercress and other aquatic plants.

Since there is no upward transpiration current, there is no necessity for the development of a woody conducting region; indeed, the absence of woody tissues is a pronounced characteristic of the group. Another reason for its absence is that it is unnecessary as a supporting structure, the surrounding water affording all the support required. The slight amount of woody tissue is always placed in the centre of the stem, for the latter must bend easily and give with the current.

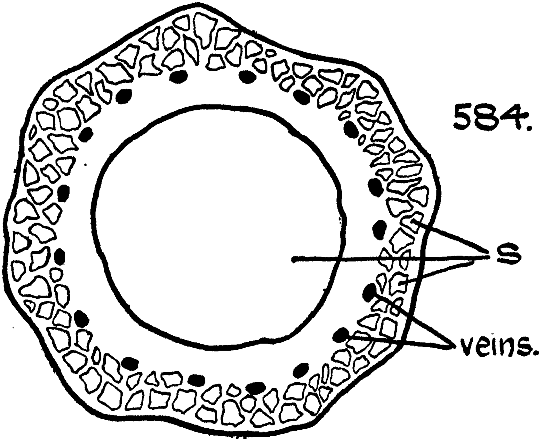
The central disposition closely resembles that of the wood in the root of a land plant, and for the same biological reason: it has to withstand a longitudinal pull. (Fig. 587.) Transpiration being entirely absent, there will be no necessity for stomata. In terrestrial forms we found the stomata were used as:—

(*a*) Exits for water vapour;

(*b*) Entrances for oxygen and exits for carbonic acid gas in respiration;

(c) Entrances for carbonic acid gas and exits for oxygen in photosynthesis.

We therefore note that stomata are also unnecessary in submerged parts of water plants since there is no gaseous entrance or exit, the gases being in solution. Further, any submerged stomata would allow the entrance of liquid into the air-space system of the plant and respiration would be interfered with. If the whole submerged surface is acting as an absorptive area it follows that waterproof cuticle, cork, and bark will preclude



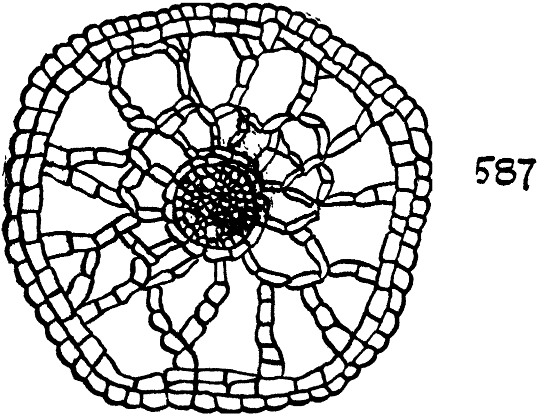


Fig. 584.—Marsh Marigold Stem. A marsh plant. Stem cut across to show the central large cavity and the system of smaller spaces (*s.*) lying in its cortex.

Fig. 587.—Potamogeton. A true aquatic plant. Note the reduction, and the central disposition, of the wood of the stem. N.B.—Also the greatly developed air reservoirs.

absorption and so starve the plant. They are therefore uniformly absent. The leaves of water plants are specially worthy of study. All the above remarks have applied particularly to plants submerged by water. We must bear in mind that frequently the leaves float on the surface of the water and sometimes they stand out beyond it. We have thus three main forms: aerial, floating, and submerged leaves, differing both in shape and internal structure. The aerial leaves have practically the same structure as the leaf of a terrestrial plant. If they are floating leaves which have been left dry by sinking of the water level, they have the structure detailed immediately below.

The floating leaves are generally oval or circular in outline, otherwise they are subdivided into more or less oval lobes. An absence of notches or indentations characterises their margins, which also frequently turn up. Usually their upper surface is glossy, often waxy. If submerged by a rise of water level, the leaf stalks grow and bring the leaves to the surface again. All the above characteristics have one object, that of preventing the wetting of the upper surface. This is rendered necessary because these floating leaves have stomata on their *upper* sides, to allow the entrance of oxygen and carbonic acid gas. The floating stem of Duckweed (Fig. 586) is very similar to a floating leaf. The most remarkable floating leaf in the world is that of an African Water-lily (Victoria regia). The leaves are immense circular discs, measuring yards in diameter. The stalk is situated centrally below the leaf. The leaf edge is upturned all round and the whole circumference is protected from animal attacks by being fortified on its outer side with a formidable armour of spines. This leaf is so large that it can easily support a man.

The submerged leaves of aquatics possess a totally different appearance. They are either long and narrow, easily bending with the current, or they are much divided into narrow finger-like parts, closely resembling branching-root systems (Figs. 589, 590.) This is not remarkable when we bear in mind that they are performing the absorptive work of roots, and so we should expect them to present a root-like appearance. In them cuticle and stomata are entirely absent, as mentioned earlier in the section.

The same water plant may possess different kinds of leaves. Good examples are found in the Arrowhead, whose leaves are arrow-shaped, oval, or ribbon-shaped, according to their aerial, floating or submerged position, and the Water Buttercup, whose floating and submerged leaves are lobed and greatly subdivided respectively. (Fig. 589.) One final point about this biological group of plants is the means by which they

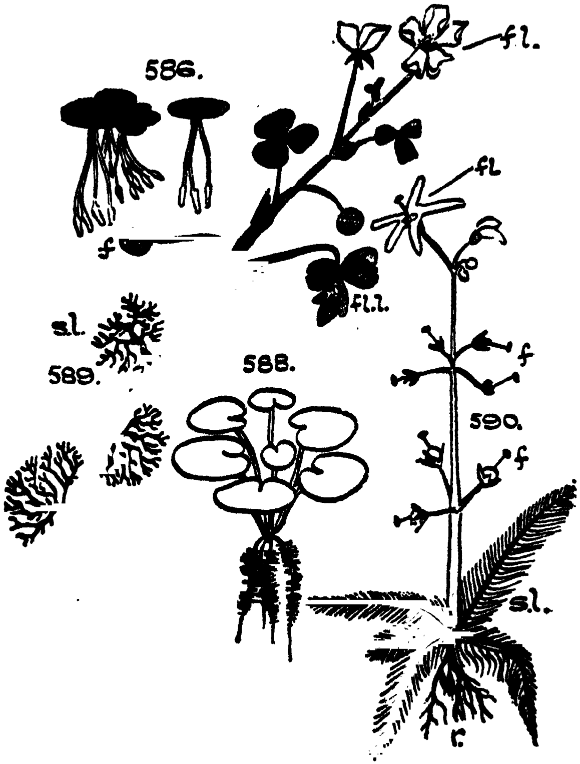


Fig. 586.—Duckweed. A group of floating Plants; also a single one. The stem is a circular green disc, from the lower side of which roots arise and hang vertically in the water. Each root is provided with a terminal "root cap."

Fig. 588.—Floating Pondweed. The regular outline of the floating leaves is noteworthy. The leaves form very good "mosaics." The roots possess absorptive root hairs.

Fig. 589.—Water Buttercup. Flowering and Fruiting Plant. (*fl.*) Flower; (*f.*) Head of Fruits; (*fl.l.*) Floating Leaves; (*s.l.*) Submerged, much divided Leaves. A free-floating water plant.

Fig. 590.—Water Violet. An attached water plant growing at the bottom of a pond. Submerged leaves (*s.l.*) are greatly divided; Flowers are pale mauve in colour; Fruits (*f.*) are usually submerged.

hibernate. Their life is necessarily at a standstill when ice covers pond surfaces, or when coldness of the water hinders their nutritive processes. Sinking is the uniform rule: either the whole plant sinks or it may produce special sinking buds. Many attached plants burrow through the mud by means of long creeping stems and frequently produce tubers or storage stems. Altogether aquatic plants offer unrivalled opportunities for studying the correlation between a plant's structure and its environment. We can find also, in marsh plants, intermediate forms possessing in a slighter degree those very structural characters which so evidently fit aquatics for their peculiar habitat.

2. **Temperature and its Conditions.**—The broad zones of vegetation found occupying the globe in different latitudes are closely connected with temperature conditions. In the Tropics an intensely hot day is followed by a very cold night, and plants must be able to endure both. In the Frigid zone, on the contrary, extreme cold is prevalent throughout the year. Even during the short summer the ground remains frozen hard at a little depth from the surface. This coldness of soil exercises a strong benumbing action on the root hairs and prevents water absorption. The optimum soil temperature is never reached; only xerophytic plants have any prospect of surviving such adverse climatic conditions. These arctic conditions are reproduced high up on mountains. Both arctic and alpine floras agree very closely. If any mesophytic plant grows there, even in a sheltered spot, it is stunted in its growth consequent on the coldness of the soil. The dryness of mountain air greatly increases the rate of transpiration, and further renders imperative the production of xerophytic characters. The blasting effect of the cold winds can frequently be seen in the shapes of trees exposed to them. Comparatively few branches are produced on the exposed side, plants thus "endeavouring" to shield themselves. Sometimes the wind takes the form of a hot blast, having previously traversed a continental desert. The "back plots" in the Australian colonies are good examples, so is the devastating effect of the winds blowing across Egypt and India from the Sahara and Gobi deserts. Temperature is, therefore, largely dependent on winds. In our own country a cold north wind delays the appearance of plants above the soil. The best way to study the effects of temperature on plant growth is to correspond with a distant friend, exchanging lists of plants, the dates of their appearance above the ground, and the temperatures of the air and soil respectively. Even in one small area the student will find marked differences in soil temperatures.

The student should note that the great reason for the shedding of leaves in winter by plants in our own country is that the coldness of the soil prevents water absorption by the root hairs.

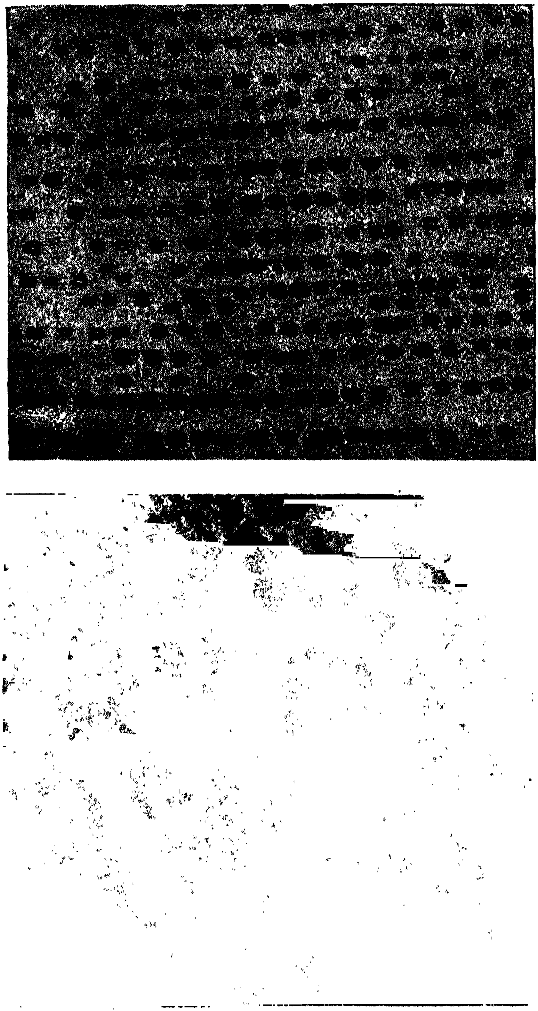
Has the depth at which a plant is buried in the soil any determining effect on the time at which it appears above ground?

In field work compare the relative dates of appearance of bulbous plants, bracken, and celandine with the times that the trees put forth their leaves. Try and explain your results by considerations of soil temperatures at various depths.

3. **Main Factors in the Distribution of Plants.**—We have hitherto traced the action of physical conditions in determining the broad distribution of plants. One or two further points require mentioning here.

(*a*) In trying to account for a plant's position we must not only take present physical conditions into account, but also those of past geological ages. For instance, how can we explain the presence of arctic plants upon the snow-covered tops of tropical mountains without calling in the help of geology? This tells us that at one period the earth's vegetation was entirely arctic in character. Subsequently warmer conditions prevailed, and the arctic plants were gradually exterminated except where they were driven to, or survived in, the intensely cold mountainous and frigid regions. Similar considerations enable us to explain that the Cedar of Lebanon is found growing wild in three isolated spots: Palestine, North African mountains, and the Himalayas. Evidently it has been exterminated by adverse climatic conditions in the intervening regions.

(*b*) Man's effect on vegetation has been immense. He cuts down forests, exterminates weeds, "improves" plants by cultivation, alters conditions of temperature and purity of the atmosphere, drains land, artificially manures it, ousts hundreds of plants to make room for one particular crop, treads down plants by his woodland and field paths, stifles them with dust from his roadways, keeps domesticated animals which browse in one region instead of roaming as they were wont, cuts railways and scatters seeds by carrying them on the footboards of his trains and so forth. In short, he upsets the "balance of life" among vegetation in thousands of ways, and plants have again to readjust their mutual relations which have been interfered with by his conscious or (more frequently) unconscious influence



Plates XI. and XII.—A Typical Hedgerow Formation (Hawthorn, Blackberry, Cleavers, Violet, Dock and Primrose); with a few of its Millions of Stomata shown above.

Every student is strongly advised to read Darwin's "Origin of Species," if not the whole, at least the chapters bearing on the above. The action of other animals in determining plant distribution is left as an exercise for the student's observation. It is too large a subject for present treatment.

4. **Typical Plant Societies.**—It is of little value to give mere lists of plants found growing in various situations.

Such lists are monotonous and are much better replaced by observations made *in situ* by the student himself, armed with one of the numerous cheap illustrated handbooks of plant life (Cassell's "Wild Flowers, and How to Find Them" is typical of many similar excellent booklets). A flora such as that of Bentham and Hooker will only be found advantageous to botanical students. What we have to emphasize in our study is plant life under various conditions. A brief synopsis follows of the conditions most likely to be found in various situations.

5. **Synopsis of Conditions under which Plants Live.**

SITUATION.	LIGHT.	MOISTURE.	TEMPERATURE.	WIND.
Hedge rows	Depending on presence or absence of trees.	Presence or absence of a ditch, slope of land.	Largely dependent on aspect.	Note vegetation on the shaded and windy sides.
Pasture	Full light, note crowding of plants and close cropping.	Variable, largely dependent on soil and slope.	Variable aspect, dependent on slope, etc., whether shaded or otherwise.	Effect of trees should be noted.
Meadows	Full light, greater variety of plants than pastures. Note times of flowering.	Generally much moisture due to flatness and low-lying character.	Cold soils usually.	Frequently sheltered by hills.
Mountain[1]	Strong	Dry usually.	Cold.	Strong.
Valley	Moderate.	Much usually.	Warm, due to cutting off of cold winds by hills and trees.	Sheltered.
Woods[2]	Very variable.	Much usually.	Warm usually.	Sheltered.

---

[1] Note variations in vegetation as higher altitudes are reached.
[2] Trace various illuminations and undergrowth.

SITUATION.	LIGHT.	MOISTURE.	TEMPERATURE.	WIND.
Walls[1]	Often strong.	Little.	Variable.	Variable.
Moors	Strong.	Variable, according to drainage. Moss moors very wet. Heather moors dry.	Extreme warmth and cold.	Strong.
Marshes	Medium to shady.	Much. (Soil saturated).	Cool.	Sheltered generally.
Ponds	Medium to poor.	Much.	More uniform than soil temps.	Frequently sheltered.
Rivers	Very variable, but never strong.	Much.	Colder than ponds.	Variable.

[1] The two sides of a wall present a good place to study two sets of conditions. Look for xerophytic characters of plants on the wall itself.

SUMMARY.

THE PLANT AND ITS ENVIRONMENT (III.).

Water Plants.

SUBMERGED PARTS absorb water, oxygen, carbonic acid gas and mineral substances by their whole surfaces.

Characters:

(*a*) External { Long slender branching stems, little root system. Much growth and little flowering. Long ribbon-like or much divided leaves.

(*b*) Internal { No cuticle nor stomata, little wood developed. No transpiration current. Great development of air reservoirs.

FLOATING LEAVES large, regular outline, glossy, stomata above, leaf-stalk capable of renewed growth.

HIBERNATION by sinking of the plant or special parts or by production of tubers and runners in the mud.

Temperature and its Conditions.—Plants grow best when living at the optimum temperature. Conditions affecting temperature:—(1) Latitude, (2) Altitude, (3) Direction and character of prevalent wind, (4) Depths of roots in soil, (5) Amount of humus and moisture in the soil.

Main Factors in Plant Distribution.

1. Climatic: Largely the result of altitude, latitude and wind.
2. Geological: Explains situations of many plants.
3. Man: most varied influence.
4. Other Animals: (herbivorous animals, birds, bees, etc.)
5. Competition between plants themselves.

Chief Plant Societies.—Hedgerows, Pasture, Meadow, Mountain, Valley, Woods, Walls and Roofs, Moors, Marshes, Ponds and Rivers.

PRACTICAL.

1. Select a small area.
2. Survey it and mark all distinctive spots.
3. Determine its slopes, water supply, character of mineral constituents and extent of organic constituents of the soil prevalent wind.
4. Map out the most dominant plant or plants.
5. Then map out carefully the distribution of smaller or less common plants. (In each case test the intensity of illumination and the amount of available water.)
6. Note how the vegetation alters in various parts.
7. Compare the dates of appearance of different plants.
8. Compare the dates of appearance of same plant in different parts.
9. Investigate the depth to which roots and underground stems penetrate the soil.
10. Carry out a series of soil temperature experiments.
11. Look for leaf mosaics and photograph them if possible.
12. Keep the same area under supervision for several years.
13. Compare the appearance, height, and weight of specimens of the same plant from different parts of district.
14. Make and compare lists of plants growing in different districts.
15. Examine plant tissues microscopically and account for differences of structure.

CHAPTER XXIII.

General Review of Plant Life.

1. **Germination.** Plants possess two well-defined classes of organs :—

(*a*) Vegetative (or nutritive);

(*b*) Reproductive.

Sooner or later some of the food manufactured by the vegetative organs is used for forming reproductive organs culminating in seed production.

The seed contains a young plant provided with all the necessary organs. It only needs favourable conditions to start growth on its own account.

The parent adequately supplies the plantlet with food in order that it may be able to grow up through the dark soil to the light, for until it does the latter, it cannot make any food for itself.

All seeds possess protective coats. The main differences in seed structure are :—

(*a*) The number of seed-leaves possessed;

(*b*) The position occupied by the nutriment (either inside or outside the plantlet).

Absorption of water is a necessary preliminary to the germination of a seed.

The water tends to enter the seed by capillarity, but its actual entrance into the living cells of the seed depends on diffusion. Seeds require oxygen for respiration, and evolve carbonic acid gas and heat in the process. Their life processes are carried on at a very rapid rate, and so they are very favourable objects by which to study respiratory phenomena. Poor drainage of the soil interferes very greatly with their breathing, since, on the ground becoming waterlogged, the ground air is expelled by water.

This ground air differs from the atmosphere in chemical composition; it contains less oxygen and more carbonic acid gas, besides being always saturated with water vapour. It is thus less suitable for respiration than the atmosphere, but this disability is greatly reduced by its constant state of motion. Its movements depend on slow diffusive currents of its constituents, and also on climatic conditions.

A supply of oxygen and moisture is not sufficient to effect the germination of a seed. A plant's vital functions can only be performed within a certain range of temperatures, and germination is no exception to this rule.

It proceeds at a most rapid rate when, *ceteris paribus*, the optimum temperature is present. This varies with different plants—an arctic plant is able to germinate and live at a temperature which would be fatal to one whose ancestors have habitually lived in a tropical climate.

The temperature to which a seed is subjected largely depends on the depth at which it is planted in the soil. This depth is possibly limited also by consideration of the size of the seed and the sturdiness of the stems produced.

Seedlings behave very differently in their emergence from the seed-coat. Frequently the seed-leaves never come out from the seed, in other cases they appear above ground and aid in food formation, thus amplifying the store provided by the parent plant. The seed-leaves are frequently distended by nutriment whilst in the seed, but this is by no means always the case, for the young plant may be embedded in food laid up for its use in other parts of the seed.

If only one seed-leaf be present, it subserves the important function of secreting digestive or fermentative juices which render the stored food soluble, and consequently available for the plantlet.

It is usual for the parent plant to provide both nitrogenous and non-nitrogenous organic food in the seed for the use of its offspring. Such dual provision is specially necessary when we consider that all food-stuffs become integral parts of the protoplasm, and non-nitrogenous organic foods are regarded by many as highly combustible and energy-producing.

Interesting parallels of parental provision are found on the animal side, where the ideal foods, milk and eggs, both contain nitrogenous and non-nitrogenous constituents.

Another noteworthy parallel is that whatever food is stored up, by either the animal or vegetable parent, it is of no use to the offspring until it has been digested. These considerations, together with the identical vital powers exhibited by both animal and plant living material, lead us to the conclusion that the protoplasm of one cannot essentially differ from that of the other form of life.

2. **Roots.**—The two main functions of roots are anchorage and absorption, and their branch systems, whether of a fibrous or tap-root formation, fit them admirably for their work. In England the two other functions of storage and climbing are occasionally performed by roots.

The storage function is subserved by the tap roots in biennials, the roots being greatly swollen to contain the food manufactured by the leaves in the first year of growth, and shrivelling greatly during the second year, when the nutrition is abstracted for the purpose of building up a long flowering stem.

The small clinging roots of ivy enable the plant to raise its leaves to a greater height than they could have been raised by the slender stem unaided.

The root is a specially sensitive organ. Its absorptive and anchoring work is greatly assisted by the marked responses evoked by gravity, moisture and other stimuli.

Roots bear root-caps at their tips to prevent their delicate growing regions being injured by friction with the particles of soil. Such root-caps remain of a uniform thickness, since new layers are added to them from within to compensate for the external loss by abrasion.

The root hairs—delicate outgrowths from the outermost cells of the root—are the true absorptive regions. These are produced only in the "twigs" of the whole root system; they possess delicate cell walls, and water is attracted through them by osmotically active substances lying within the hairs. Young roots have their woody water-conducting tissues aggregated towards the centre. By this disposition of the strong tissues the organ is best able to withstand the longitudinal pulls to which it is subjected.

Since roots grow in a very resistent medium, it is imperative that young roots should be protected adequately from mechanical injury during their most delicate early stages.

Roots effect this by sending out their young members from a deeply-seated region; the rootlet grows some distance through its parent before it reaches the hard soil particles.

Returning to the action of the root hair: these organs become strongly distended with osmotically absorbed sap, and gradually this turgid condition extends until the entire root cortex is in a state of distension, then the juicy cells abutting on the wood of the root, suddenly allow their water to escape into the latter. A rhythmic pumping action is thus brought about, and this expresses itself in root pressure or upward forcing of water from roots into stems. Root pressure is far from being a uniform force: it varies with the season, the time of day, the temperature of the soil, and the amount of soil water available. The force of root pressure is immediately due to the pumping action of the root cortex, but primarily it owes its origin to absorption by the root hairs.

Water absorption is due to the presence of an osmotically active acid sap in the root hairs; mineral absorption depends first on the relative solubility of the minerals, but later on the extent to which such minerals are utilised by the plant in its chemical processes.

From this it follows that during the later part of its life a plant only absorbs the mineral substances actually required, or, in other words, exercises a "selective" action in its abstraction of minerals from the soil.

In order to be continuously surrounded by soil containing the requisite water and mineral substances, it is necessary for the root continuously to increase in length, and so lay new soil areas under contribution.

This growth in length is not uniform throughout, but is limited to the region just behind the tip proper.

3. **The Stem.**—The main stem functions are the conduction of food and food materials and the presentation of theleaves to the light.

We can easily judge from the girth of a stem and the extent of its external protective structures whether the plant to which the stem belongs is an annual, or a biennial, or a woody perennial. All stems arise from buds, and these are protected by leaf stalks in their early stages.

When the leaves fall from a tree the buds have already developed protective structures (scale-leaves, resin, hairs, etc.) for themselves.

The most remarkable thing about buds is the wonderful way in which the leaves, and also (in spring-flowering plants) the flowers, are packed away. No space is lost; the bud is filled to its utmost capacity.

There are three distinct conducting tissues in stems:—

(*a*) The soft juicy cells which are the path for transport of sugar.

(*b*) The woody strands, serving for distribution of water and mineral substances.

(*c*) The softer strands (the bast) which conduct elaborated nitrogenous foods.

The last two are manifestly elongated and otherwise altered so as to carry out better their transporting function, hence they are generally meant when conducting tissue is referred to.

In green stems they are in the form of isolated strands, but in woody stems the actual conducting region takes the form of a hollow cylinder.

Some plants (perennials) live many years. In some members of this group the plant dies down to the ground each year, coming up every spring from an underground stem, or rootstock. In other perennials the stems remain above ground and increase in girth by the activity of their cambial layers. This thickening of the woody region enables the stem

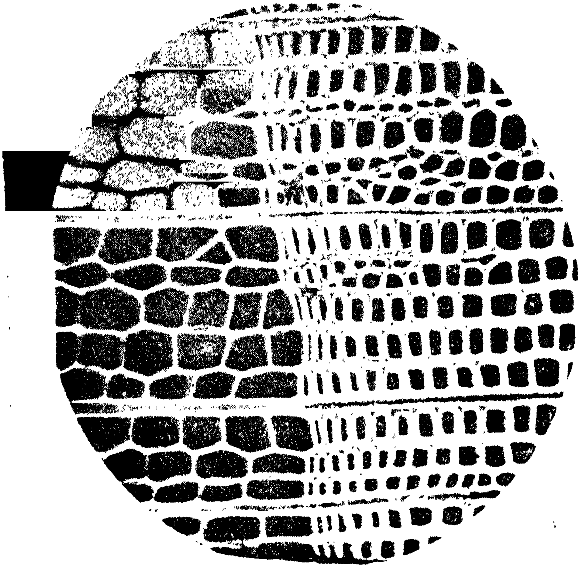


Plate XIII.—MICRO-PHOTOGRAPH of a small part of an Annual Ring of PINEWOOD in TRANSVERSE SECTION.

N.B.—The sharp distinction between Autumn and Spring Wood. (Four medullary rays are shown.)

to give a greater support and a larger supply of water and mineral substances to the ever-increasing number of leaves borne on it.

In a cross section of a woody trunk the yearly increases of wood are clearly indicated by the annual rings, whose concentric circular system is due to the fact that the wood formed in the earlier part of the year is much looser in texture than that produced later. (Plate xiii., page 277.)

Radiating out from the central pith of such a stem are the medullary rays—thin lines of living cells embedded in the wood. These are specially useful for storage of starch between the intervals of growth. The bulk of a woody stem is composed of dead cell-walls subserving protective, conducting or supporting functions; the only living parts of a thick stem being the medullary rays and the cambial region lying between the bark and the wood.

The herbaceous perennials frequently detach portions of their stems for the purpose of reproduction. Tubers, bulbs, and corms are the usual structures produced for this. They all betray their stem nature by bearing leaves and buds, although they are liable to be mistaken for roots by their underground positions. In all these parts the parent plants store up a large amount of food to provide their offspring with sufficient material and energy to commence a vigorous and independent existence. In tubers and corms the stems act as food reservoirs, whilst the leaves are the seats of storage in bulbs. Starch is the usual storage material in tubers and corms, sugar in bulbs.

In their response to external stimuli, stems show that they are exceedingly sensitive to the influence of light. The latter exerts a *directive* influence on the growth of the stem-tip, although the main action of the stimulant is to check the growth in length.

Light retards, darkness accelerates, growth in length of stems. This phenomenon is especially useful in enabling a young shoot to grow quickly through the dark soil—a great advantage when we remember that no food can be manufactured by the plant until it is so placed that it can absorb the incident light.

Only certain stems react to the stimuli of gravity and contact; main stems being responsive to the former stimulus, twining stems to the latter. Plants seem able to convert almost any organ into a tendril if necessary. The tendril behaves in a manner perfectly fitting it for its work; it nutates and " finds " a supporting structure, it clasps this, it drags the plant slightly upwards, it lastly forms a strong elastic spring-like attachment. Only plants with rather weak stems provide themselves with tendrils. By means of the latter they are able to place their leaves in more favourable positions to receive sunlight.

4. **The Leaf.**—This, the plant's essential food-making organ, betrays the nature of its work by its appearance both to the naked eye and under the microscope. The arrangement of the leaves on the stem, their stalks, their shapes, their veins and thin green tissue all help materially in rendering them more efficient chemical or food-making factories.

The microscope shows us a similar fitness of things in the minute structure: the epidermis, cuticle, veins, soft green cells, chloroplastids, air spaces and stomata, all help to form a perfect food-making machine.

It is only by possessing chlorophyll that the leaves are able to manufacture sugary food. Sunlight is necessary for the formation of chlorophyll, as well as for sugar production by the latter. Favourable temperature conditions are also necessary, as well as an adequate supply of the requisite raw food materials. Potassium salts evidently play some part in the photosynthetic process, for it cannot proceed in their absence; similarly, no plant can turn green unless iron salts are present. By this food-making process plant life purifies the atmosphere by removing carbonic acid gas and replacing it by oxygen. This food-making process, which purifies the air during daylight, must be clearly distinguished from the plant's breathing process. The latter is always going on and fouls the air whenever photosynthesis is not the more active of the two processes.

We usually judge of a leaf's food-making activity by testing the amount of starch present. This is not the first formed food. It is a temporary storage form of sugar when the latter is being made too rapidly to be removed from the leaf. Leaves are starch free in early morning, they show good starch reactions in bright afternoons and evenings, and they are rendered starch free during the night, so that they may be able to carry out the next day's work of food formation. Starch or sugar formation only represents the first stage of the plant's elaborative or formative processes of food making. We find fats and proteids in plants; these necessarily must have been made by further chemical changes and successive elaborations.

In the synthesis of proteid food an incorporation of mineral substances (sulphates, phosphates, nitrates) is necessary. These substances can only be taken in by the root hairs in extremely dilute solutions, hence it is necessary for the plant to absorb an excess of water in order to gain the requisite amount of mineral matter. The watery excess is got rid of by transpiration, a vitally modified evaporation going on from the leaves.

The upward current, transpiration current, or ascending sap, supplies the water given off in this way. It may rise as a series of isolated currents or as one of cylindrical form. Its rate is subject to much variation consequent on varying conditions of temperature, illumination, wind and humidity. The modifications produced by these agents can be very well shown by simple experiments with the potometer.

5. **Flowers and Fruit.**—The essential parts of flowers are the sexual organs (stamens and ovaries) and their contained sexual cells (pollen grains and egg cells). All other parts are accessory, being either for protective or attractive purposes.

By a sexual process, or fusion of two sexual cells, the plant produces a descendant which, though small, is endowed with great potentialities of future development and growth.

The student should clearly distinguish between vegetative and sexual reproduction. In the former variety there is no previous cellular (or more correctly nuclear) fusion. In the latter the female or egg cells, being enclosed in ovules and these in closed ovary chambers, are quite out of reach unless the pollen grains are deposited on the ovary wall and grow down to them. Pollination is the placing of the pollen grain on the stigma or receptive surface of the ovary wall. Generally, the pollen has been brought from another flower. Cross pollination of this kind is more advantageous to the plant than self pollination, although the latter is preferable to no pollination whatever. Plants utilise the wind and insects as their normal agents for pollen transference.

Full details of the expense to which plants are put to obtain pollen dispersal by either of these agents have already been given in Chapters xvi. and xvii. It is only necessary to emphasize that plants must pay a price for cross pollination, and that in general the advantage accruing from it is greater than the expenditure of material to obtain it. The best way to study flowers is merely to consider them as means to a definite end, *i.e.* seed production.

The complexity of floral structures is best interpreted by their being regarded as pollination contrivances, whilst cross and self pollination should be read in the light of seed production.

Before an ovule can develop into a seed its contained egg cell must be fertilised. Fertilisation may be said loosely to consist of the fusion of the tip of the pollen tube with the egg cell; strictly, it consists of the fusion of the nucleus of the egg cell with a nucleus from the pollen tube. The egg cell then develops into a young plant, which is sometimes embedded in nutrient material, but is always covered externally by a protective seed-coat derived from the ovule wall. The wall of the ovary chamber plays a large part in seed dispersal, becoming fleshy, woody, prickly or hairy, according to the means adopted for scattering the young plants. When the wind is the agent for scattering seeds or fruits, we generally find them either small, or if large, provided with wing or feather contrivances. Many seeds can only be scattered in a high wind, others again require no wind at the time, for they are propelled violently from the parent by catapult or explosive mechanisms.

Many plants invite the conscious or unconscious aid of animals in scattering their seeds. Good examples of the latter are the carriage of burrs in the fur of animals and of small seeds embedded in the mud on the feet of water fowl. Birds are specially catered for as seed scatterers, the seeds of the fruits being either small and capable of passing uninjured through their digestive tracts, or so large that they are ejected from the mouth. The chief animal attractions lie in the colour, size, fleshiness, and edible nature of the fruits.

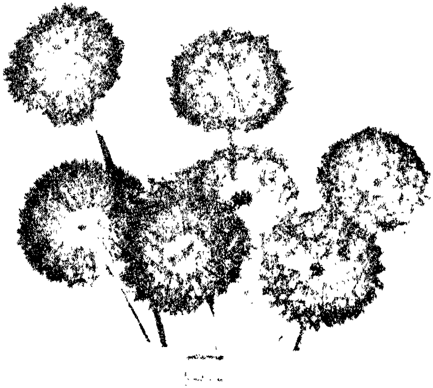


Plate XIV.—DANDELION CLOCKS: NATURE'S AIRSHIPS.

6. **Plant Ecology.**—Plants are only able to exist in a given spot if they can—

(*a*) Fit themselves to the physical conditions.
(*b*) Hold their own against animal attacks.
(*c*) Successfully compete with other plants growing in the vicinity.

The optimum temperature is very seldom attained, plants must frequently survive extremes of heat and cold. The temperature is determined by latitude, altitude, exposure, and characters of wind and soil. It varies largely even within the bounds of a comparatively small area. It varies at different depths of the soil, and also with different degrees of shade, so we may fairly say that no two plants in the same district are subjected to the same temperature conditions. It must be borne in mind that the greater the divergence of the temperature from the optimum, the more sluggish is the plant in manifesting any one of its activities. The student should apply this last statement to just one function (*e.g.* the photosynthetic) and see what far-reaching effects will follow as a natural result from the activity being slowed down by a divergence from the optimum temperature.

In their struggle for light and air plants compete very keenly with one another, because their stems and leaves present themselves to the air in the same way. It is the identity of their necessities which renders the struggle for existence so sharp.

A successful plant always shows certain structural features in a more pronounced degree than its less favoured fellows. These structural modifications are the identical ones which fit the plant for life in its particular environment and which have been the direct cause of its success. In no part of plant structure do we find greater modifications than those by means of which the amount of water absorbed or lost may be regulated.

The student is strongly advised to group xerophytic and hydrophytic characters in parallel columns so that they may be contrasted with the character exhibited by any ordinary terrestrial plant. He will then see clearly how modification of the same part has proceeded in two opposite directions in order to better subserve two opposite functions. One good example is seen in the absence or exaggerated development of the cuticle in the two biological groups. In ecological work no physical condition is to be overlooked. It may have an important influence on the performance of some particular plant function.

If the geological, physical and biological surroundings are thoroughly investigated, hidden causes become quite obvious, and throw into strong relief the fact that a plant can only thrive when it places itself in harmonious relationship with its ever varying environment.

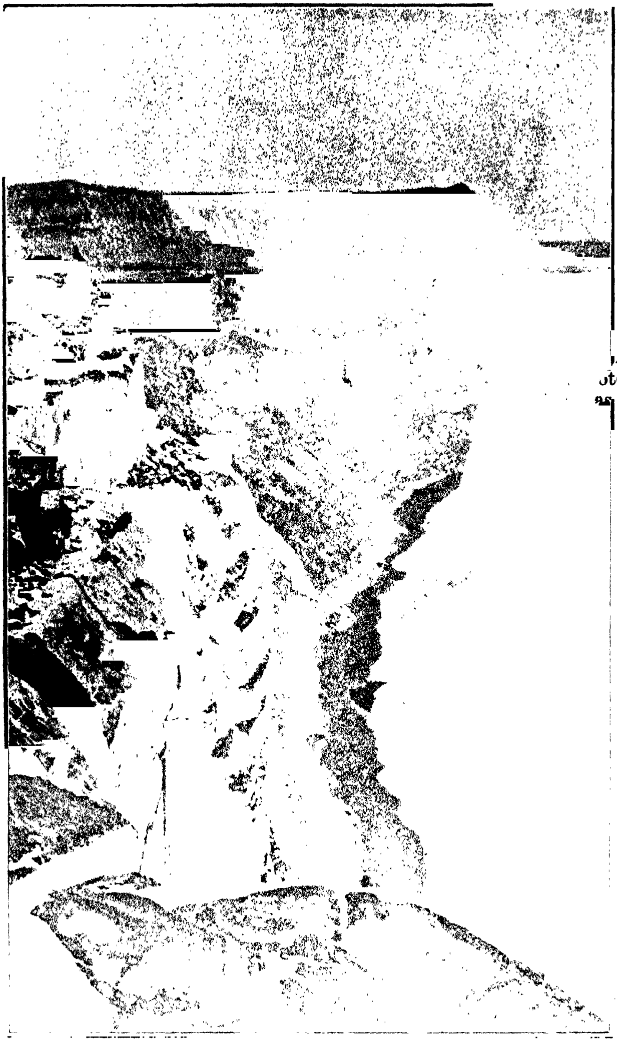


Plate XIVa.—A Canon of the Colorado, U.S.A., showing River Action.

PART II.

THE SCIENCE OF THE SOIL.

CHAPTER XXIV.

The Formation and Geological Origin of Soils.

1. **Soil and Subsoil.**—No course of plant study would be complete without some reference to the nature of the soil. A plant derives its food from the soil and the air, whilst an animal lives upon food derived from plants. There must, therefore, exist in soils, air, plants and animals, substances common to all. This leads us to consider in some detail the origin and composition of soils.

What is soil? It is the name applied to the more or less powdered matter forming the upper layer of the earth's land surface. As a rule the soil is quite shallow, but there is a gradation downward into what is called the subsoil, and thence to the rock beneath. The subsoil differs from the soil above it in texture, colour and composition, while the nature of both the soil and subsoil is largely determined by the character and composition of the rock from which they are formed. The subsoil is generally coarser in texture, lighter and brighter in colour, and contains much less plant food than the soil proper. This contrast is largely due to the chemical processes of oxidation and hydration which take place wherever the air penetrates. The variation in colour depends upon the degree of the oxidation and hydration of the iron which is present in most soils and subsoils in small quantities.

2. **Formation of Soils.**—Soils are formed from rocks by decomposition and disintegration—processes which are generally known by the name of weathering. All rocks alike, from the hard crystalline granite to the soft shale, are acted upon by the various natural agencies, and sooner or later reduced to soil. These agencies are sometimes classed as—

(i.) AQUEOUS, or those arising by operations of water. These include the action of rain, rivers and ocean, as well as ice action.

(ii.) ATMOSPHERIC, or those operating through the medium of the air.

(iii.) CHEMICAL, or those resulting from the chemical action of substances upon each other—especially the action of oxygen and carbonic acid.

(iv.) ORGANIC, or those depending upon vegetable and animal growth.

(v.) IGNEOUS or VOLCANIC, agencies common only in volcanic areas.

(i.) AQUEOUS AGENCIES.

(*a*) *Water* acts both chemically and mechanically. Water alone will dissolve several rock-forming minerals, but in the great majority of cases the solution is effected through the medium of carbonic acid gas, which is dissolved from the air. Thus the rain will soon efface an inscription from a marble or limestone tombstone, and by the same action many of the mineral components of the rocks are decomposed, and hard stone is transformed into sand and clay. The mechanical effect of water is even greater than its solvent action, especially when it carries matter like sand and grit in suspension. The action of rivers in wearing down rocks, and cutting their channels is evident in every country. A sudden heavy shower soon renders the clearest stream turbid with particles or sediment derived from the rocks over which it flows. The rivers receive this mineral débris from the brooks and mountain streams, and carry it down into the valleys, and often by flood distribute much of it over the plains as an alluvial soil. All large rivers flow during a portion of their course through fertile alluvial plains which have been formed by the continuous supply of mud brought down from the higher grounds and deposited at a lower level where the river loses much of its transporting energy. This is also noticeable as the river widens towards its estuary or mouth, where in many cases an extensive delta has been formed. Perhaps the best examples are seen in the Ganges of India, and the Mississippi of North America. It is calculated that the Mississippi carries into the sea about 400,000,000 tons of mud annually. This would form a block of earth 268 ft. in height, with a base of one square mile.

Plate XV.—WEATHERING OF STRATIFIED ROCKS BY RIVER AND SEA (ISLE OF WIGHT).

The soil brought down annually by the Ganges would cover the whole of Wales with a layer of earth two feet thick. This is irrespective, too, of the immense amount which must also be deposited at various points in the river's course, and, further, it does not take into account the amount of matter which is carried in solution, some of which sooner or later may be thrown down by precipitation. The Thames carries past Kingston 19 grains of mineral salts dissolved in every gallon. This is equivalent to 1502 tons every twenty-four hours, or 548,230 tons every year.

(*b*) *Frost.*—Besides the direct action of water, there is the power it exerts when it freezes. If water is imprisoned in the crevices of the rocks when the frost comes, the freezing water acts as a powerful wedge and disintegrates particles on the surface, or enormous masses from the face of the cliff or mountain side. By repeated action, the frost will gradually break up and pulverise large blocks of rock, especially where the rock is of a porous nature, or where soft and unstable minerals in the rock mass weather away and allow the water to enter the crevices. Further the frost acts upon the soi itself, and is a most useful natural agent in tillage.

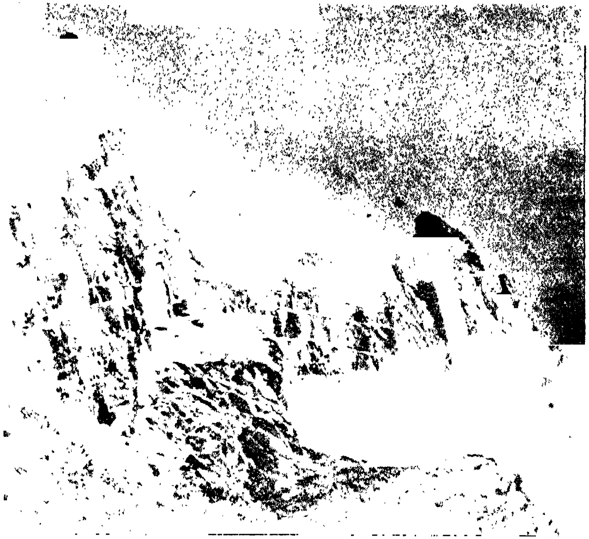


Plate XVI.—ACTION OF SEA ON HARD ROCKS (TORQUAY).

fragments of solid rock, which are finally crumbled or reduced to powder. The waves of a rough sea will easily "pick up" a block weighing ten tons and use it as a battering ram against the face of the cliff, a process which in the end leads to mutual destruction. The writer has witnessed this "marine artillery," as Playfair called it, on the South Devon and Cornish coasts, where in a strong sea, masses of rock of several tons in weight are washed about like pebbles. The action of this erosion is in most cases entirely destructive, but sometimes the débris forms a new tract of alluvial soil. Examples of this may be seen in the neighbourhood of the Isle of Sheppey, or on the coast of Somerset, where a large tract of marine clay has been formed, backed by a line of hills which probably formed the actual coast line at some distant time.

(*d*) *Ice Action.*—This is chiefly seen in the case of glaciers. These "rivers of ice" creep slowly downward from the mountains into the valleys. Glaciers act in two ways:

(1) They carry the débris of the mountains down to lower levels; and
(2) They erode their beds.

When the ice melts upon reaching warmer zones, much of the ice-borne matter is deposited as a "moraine," but the stream which issues from the glacier is milky or turbid, with suspended matter. Sooner or later a great deal of this matter is deposited in the form of alluvial soil. In many cases it is carried into a lake, and, sinking to the bottom, in the course of time it will gradually convert the lake itself into an alluvial tract. From the end of the Aar glacier in Switzerland, it is estimated that 440 million gallons of water escape every day, containing 280 tons of suspended matter.

(ii.) ATMOSPHERIC AGENTS.—The atmosphere is another important factor in bringing about the disintegration and decomposition of the rocks. As in the case of water, it acts both chemically and mechanically. The oxygen in the air attacks the mineral constituents and forms softer compounds, and the carbon dioxide slowly converts the harder compounds into soft and semi-soluble carbonates. The mechanical action of the air is more important than is frequently supposed, the wind acting like a sand blast upon the surface of the exposed rocks. The wind also increases the force and consequent action of the waves upon the coast of a country.

A mere change of temperature, irrespective of actual freezing, is also an important factor in the formation of soil. Most bodies expand under the influence of heat, but few to the same degree. Thus, when a rock is composed of several minerals which expand differently through the same range of temperature, the change acts more powerfully than when the rock is homogeneous and expands equally in all parts of the mass. The range of temperature in England often gives a difference of 50° or 60° F. between day and night records. This change tends to crack the *surface*, and sometimes the *substance* of the hardest rocks, and thus prepares the way for the subsequent action of the rain and frost.

(iii.) CHEMICAL AGENCY.—This has already been referred to briefly in connection with the action of air and water. The typical chemical weathering of granite will be dealt with later.

(iv.) ORGANIC AGENCIES.

(*a*) *Vegetation.*—Plants growing where the soil is shallow act on the rocks below in several ways. Mechanically, by sending their roots into the crevices they wedge the rocks asunder as the roots increase in diameter—a force far greater than at first imagined. Further, lowly plant life generally brings abundance of moisture, which dissolves the carbonic acid, as well as certain organic acids, from decaying vegetation, and this easily softens the rock beneath and deepens the soil. A small amount of acid is generated in the roots themselves, escapes from them, and increases chemical action.

(*b*) *Animals.*—Some animals play an important part in the formation of soil, chiefly by opening up the surface and allowing air and water to penetrate and circulate more freely. The common earthworm feeds on decaying vegetable matter, and takes in with his food large quantities of earth. This earth is profoundly changed in passing through the body of the earthworm, and much of the matter excreted in their castings is in a useful form for plant food. Darwin calculated, after careful observation, that the earthworms normally found on an acre of land would pass ten tons of earth through their bodies annually, bringing up portions of the dormant soil (or subsoil) and depositing it on the surface in the form of characteristically coiled castings.

In the same connection Darwin found that in fifteen years a layer of marl had been buried under three inches of a fine dark loam by the action of the earthworms.

Burrowing animals, by throwing up the soil and subsoil, serve the same end. In some parts of Cape Colony wide areas of open country are infested with small mole-like animals, which bring up the soil and bury the growing vegetation under it. It is well known, too, that the beaver indirectly brings about the formation of large tracts of fertile soil, by checking the flow of rivers or diverting their channels. In the United States, in the neighbourhood of the Rocky Mountains, thousands of acres in many of the valleys have been converted into lakes. These lakes, intercepting the sediment carried down by the streams, and being invaded by marshy vegetation, have subsequently become morass, and finally meadow land. Geikie says that in these regions the alluvial soils of the valleys have been modified and extended by the operations of the beaver in an almost incredible manner. There is also evidence to show that many fertile tracts of soil in this country have had a similar origin, beavers being quite common in England within historical times.

(v.) IGNEOUS AND VOLCANIC ACTION.—In volcanic districts large tracts of soil have been formed from the weathering of the lava, as well as from the volcanic dust which is ejected in great quantities. Lava slowly crumbles into a fine fertile clay. This is brought about by—

(*a*) The rapid cooling of the surface of the lava stream.
(*b*) The formation of a cindery porous mass.
(*c*) The gradual yielding to the influences of moisture and changes of temperature.

3. **The Relation of Minerals, Rocks and Soils to One Another.**—The composition of any soil is largely determined by the composition of the rocks from which it is derived, as well as the conditions of weathering. But we shall see later that although the character of a soil depends primarily on the nature of the rocks out of which it has been formed, its fertility arises in no small measure from the admixture of decayed animal and vegetable matter with the decomposed rock.

Rocks are composed of MINERALS, which may be

(i.) Chemical elements, in an impure state, like sulphur rock.
(ii.) Simple chemical compounds, ike quartz.
(iii.) Complex chemical compounds, like mica and felspar

By far the greatest number belong to the last class. The student should endeavour to acquaint himself with a few examples, and if possible to obtain specimens.

CLASS I. IMPURE CHEMICAL ELEMENTS, *e.g.*:

(*a*) GRAPHITE. A form of carbon found in ancient crystalline rocks and some old limestones, also as a rock mass. Some forms of coal (*e.g.* anthracite) are almost pure carbon.

(*b*) SULPHUR. Found in volcanic regions. In Sicily there are alternate beds of sulphur and limestone.

(*c*) IRON, which occurs in small quantities in some rocks. Generally, it is combined with other elements.

CLASS II. SIMPLE CHEMICAL COMPOUNDS, *e.g.*:

(*a*) QUARTZ, which is extremely common in many crystalline and some stratified rocks. It is chemically composed of silicon dioxide (SiO_2), and is by far the largest constituent of sandy or gravelly soils.

(*b*) HÆMATITE is a common oxide of iron. Compounds of iron may be regarded as the chief pigment or colouring matter of the soil and subsoil.

(*c*) PYRITES is a fairly common mineral, consisting of iron combined with the element sulphur. As it weathers it also colours the surrounding rock or soil yellowish brown or red, commonly seen in the disintegration of a chalk rock, in which pyrites often occurs.

(*d*) CALCITE, which is crystalline carbonate of calcium ($CaCO_3$). It has the same chemical composition as pure chalk, and is easily dissolved and redissolved out of the rock by water, especially when such contains carbon-dioxide in solution.

CLASS III. COMPLEX CHEMICAL COMPOUNDS, *e.g.*:

(*a*) FELSPAR, composed chiefly of silica, alumina, with a smaller proportion of potash, soda or lime. It is an essential constituent of granite and many other crystalline rocks. It is softer than quartz, with which mineral it is so often found. An ordinary pen-knife will scratch the opaque crystals of felspar in granite, but not the semi-transparent quartz crystals.

(*b*) MICA is a soft mineral, readily split into thin transparent plates. There are two kinds—(*a*) white, (*b*) black, mica, which are mainly composed of silica, potash and magnesia, and can be easily recognised in granites by their glistening and scaly nature. White mica occurs in many sandstones, giving them a silvery appearance.

Other common rock-forming minerals are Hornblende, Augite, Olivine, Talc, Steatite (or soap stone), Serpentine (in Lizard stone). These are chiefly composed of silicates of aluminium, magnesium and iron.

The Student should also endeavour to make himself familiar with a few of the COMMON ROCKS forming the earth's crust. They may be considered under the following heads:—

Sandy (or Arenaceous) and Fragmental Rocks, *e.g.:*

(i.) SAND is an aggregation of water-worn particles derived from pre-existing rocks or flinty matter. It is generally composed of quartz grains.

(ii.) GRAVEL is a term applied to the water-worn fragments of rocks. The pebbles, which are quartzose or flinty in character, vary greatly in size. Gravel is commonly found in the subsoil, its colour depending upon the iron compounds present.

(iii.) SHINGLE and RUBBLE are terms applied to fragmentary formations, but they are more important geologically than agriculturally.

(iv.) SANDSTONE is consolidated sand, the particles being cemented together by lime, clay, oxide of iron, or some other matter. Most sandstones have been formed under pressure.

(v.) GRIT is a term applied to a sand rock when the grains are sharp and angular, and not water-worn.

Clay (or Argillaceous) Formations, *e.g.:*

(i.) MUD is the term generally applied to the fine, soft sediment deposited at the bottoms of seas, lakes, and pools, or as alluvial tracts along the courses of rivers. Most of the matter has been derived from the rocks by the various natural agencies, and it is composed chiefly of fireclay, divided débris of minerals, with a certain admixture of vegetable and animal matter. Mudstone is a term used for consolidated mud.

(ii.) CLAY is also a fine impalpable sediment from water, and consists almost wholly of alumino-silicious particles. It is usually tough and plastic—"heavy," as the farmer terms it. It differs from mud in the absence of vegetable and animal matter.

(iii.) SILT is the name given to the miscellaneous matter deposited in lakes, estuaries, and other comparatively still waters. Silt may thus consist of intermingled mud, clay and sand, or distinct layers of these, and may give rise to soils of first-rate fertility.

(iv.) SHALE is consolidated mud easily split into layers. This laminated or shaly (splitting) structure distinguishes it from beds of clay and marl.

(v.) SLATE is a rock which is much harder than shale and more consolidated. It is a clay rock, but weathers with some difficulty.

Chalky (Calcareous) Rocks, *e.g.*:

(i.) LIMESTONE is a widely applied term for all rocks, the basis of which is carbonate of lime—that is, lime in chemical combination with carbonic acid. Chalk is the name given to the softer and earthier-looking varieties of limestone. It gives rise to very shallow and poor soils, although it is used to improve heavy soils, because its admixture increases the friability.

(ii.) MARL.—This term is applied to all friable compounds of lime and clay. There are clay marls or marl clays, according as one or the other ingredient predominates.

(iii.) MAGNESIAN LIMESTONES.—Many limestones contain a small percentage of magnesia, but those entitled to the term must contain over 20 per cent. of magnesia.

Igneous (Crystalline) Rocks, *e.g.*:

(i.) GRANITE is a granular mixture of quartz, mica and felspar, varying in colour according to the presence of dark mica and according to the colour of the felspar. When the mineral hornblende replaces the mica, the rock is called *Syenite*.

(ii.) BASALT is close grained, hard, and compact. It is probably of volcanic origin, and often occurs in columns, more or less regular, as in the Giants' Causeway in the North of Ireland.

(iii.) TRACHYTE is a rock nearly allied to basalt, of greyish colour and granular appearance. Trachyte and basalt are sometimes regarded as lavas.

4. The Weathering of Granite.—It will be instructive at this stage to consider in detail the weathering of granite—as a type of the formation of soil from a hard crystalline rock.

It has been already mentioned that granite is composed of three minerals—mica, quartz and felspar. In the disintegration of the rock mass the soft scaly mica is first broken up. This allows the air and water to penetrate into the cracks and crevices so formed, and by the action of the frost the surface of the granite becomes rough and pitted and begins to crumble away. The felspar, which is composed of the silicates of aluminium, potassium, sodium, and occasionally lime, is decomposed by the chemical action of carbon dioxide (CO_2) found in the air and water. The CO_2 combines with the potash (or soda) and lime to form the carbonates of these alkalies. The insoluble silica (sand) and silicate of alumina (clay) remain comparatively unaltered. The felspar in the rock acts as a kind of cementing agent for the quartz and mica, and thus when the felspar has been decomposed the quartz and mica remain as a sand. It is interesting to note that generally when the granite weathers on high ground the resulting soil is characteristically sandy, whilst in the valley below we find a more or less heavy clay which the mountain streams have carried down from the weathering felspars of the granite rock.

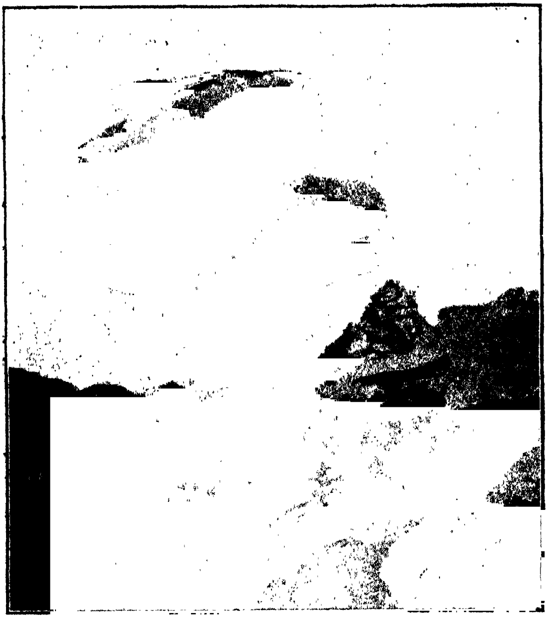


Plate XVII.—WEATHERING OF GRANITE (DEVON AND CORNWALL).

Soils formed from granites are typically shallow, except perhaps where they are found on fairly level ground, as in some parts of Devonshire, in which case it appears that all the products of decomposition and weathering—quartz or sand, silicates of alumina and carbonates of potash, soda or

lime remain to form the soil, generally an intermediate soil of good average fertility. Some kinds of granites, especially those rich in felspar, decompose to a depth of thirty or forty feet, forming a soil largely composed of kaolin or china clay. Owing to its numerous jointings granite occasionally weathers into forms that resemble ruined walls. The weathered slabs become loosened from the rock mass and slip off and expose the lower parts of the rock to the same disintegrating agencies.

5. **The Geological Origin of Soils.**—All rocks, whether hard, igneous and crystalline, like granite, or soft, aqueous and amorphous, like shale and limestone, are thus acted upon and produce characteristic soils of varying fertility. From an agricultural point of view the aqueous rocks are of far greater importance than the igneous rocks of Britain. A geological map is of great service in indicating the general nature of the soil in any locality. It must be remembered, however, that the soil which has been derived from the formation shown by the geological map, is often masked by alluvial deposits. This is especially noticeable in the neighbourhood of East Yorkshire, Lincolnshire and the Wash, as well as along the courses of the larger rivers. The nature of the soil formed from the rock is often modified too by the presence of organic matter. This will be considered later. Drift soil formed and deposited by glaciers in past ages also masks the true formations. Commonly, these drift soils exhibit all the characteristics of a stiff clay, while the subsoil is of quite a different nature. In the East of England the natural soil is much modified by the presence of glacial deposits. The admixture of clay with the lighter and looser soils of the district forms an excellent soil for arable farming.

Thus, while it is extremely instructive to consider the stratified formations in the geological and chemical origin of soil, the greater truth regarding the nature of the soil in any locality is to be ascertained by reference to a map showing the alluvial and drift deposits.

The stratified or aqueous rocks occupy nearly the whole of our island, the igneous rocks only covering small patches. They are divided according to their superposition or order of succession into primary or first formed, secondary or second formed and tertiary or third formed. They normally occur in this order, and the following table will be very useful to the student since it concisely shows the order of superposition of the principal stratified formations of England. We propose to deal briefly with the characteristic soils derived from these formations, while giving the locality in which they are best developed.

STRATIFIED ROCKS OF THE BRITISH ISLES.

Groups.	Formations.	Systems.
Alluvial and Peat Soils.	Recent.	
Glacial Deposits.		
Newer Pliocene.	Pliocene.	Tertiary.
Older Pliocene.		
Upper Eocene.	Eocene.	
Middle Eocene.		
Lower Eocene.		
Upper White Chalk.	Cretaceous.	Secondary.
Lower White Chalk.		
Upper Greensand.		
Gault.		
Lower Greensand.		
Wealden.		
Purbeck Beds.	Oolitic or Jurassic.	
Portland Stone.		
Kimmeridge Clay.		
Coral Rag.		
Oxford Clay.		
Cornbrash.		
Great or Bath Oolite.		
Inferior Oolite.		
Lias Marls and Shales.		
Lias Limestones.		
Upper Trias.	Triassic.	
Lower Trias.		
Magnesian Limestone.	Permian.	Primary.
Coal Measures.	Carboniferous.	
Millstone Grit.		
Carboniferous Limestone.		
Upper Devonian.	Devonian or Old Red Sandstone.	
Middle Devonian.		
Lower Devonian.		
Upper Silurian.	Silurian.	
Lower Silurian.		
Slates and Grits.	Cambrian.	

6. Agricultural Characters of the Formations Considered According to the above Table:—

I. Recent.

(*a*) Alluvial and Peat Soils. Alluvial soils accompany the course of rivers and occur especially at their mouths, deltas or estuaries. Good examples are met with in South-East Yorkshire, North Lincolnshire, the Fen district and Romney Marsh. There are remarkably fine alluvial soils around Boston, Spalding, and Long Sutton in Lincolnshire. Good examples of peat soils are also found in Lincolnshire, as well as in Bedfordshire, Cambridgeshire and Huntingdonshire.

(*b*) GLACIAL DEPOSITS. These have already been referred to as masking the underlying rocks. It is only when mixed with other soils that they can be described as fertile, the actual deposit giving a poorer soil than might be expected.

II. Tertiary Formations.

(*a*) PLIOCENE, represented by the Suffolk crag which forms a narrow strip of fertile land in the south-east of Suffolk. When blended with the soils of the "London clay" (lower Eocene) gives a particularly fertile soil.

(*b*) EOCENE. Marine and freshwater clays, marl and limestones represent the upper and middle Eocene in the northern part of the Isle of Wight, while the lower Eocene is represented by the London clay formation, which yields a soil of tenacious brown and bluish grey clay found in South-East Suffolk, most of Essex, North Kent, South Berks, South Hampshire, and covering nearly the whole of Middlesex. Being a very heavy soil it is expensive to work, but may be much improved by application of chalk, which is often in the vicinity. When so treated it makes excellent wheat land. Much, however, of the London clay is left as grass land.

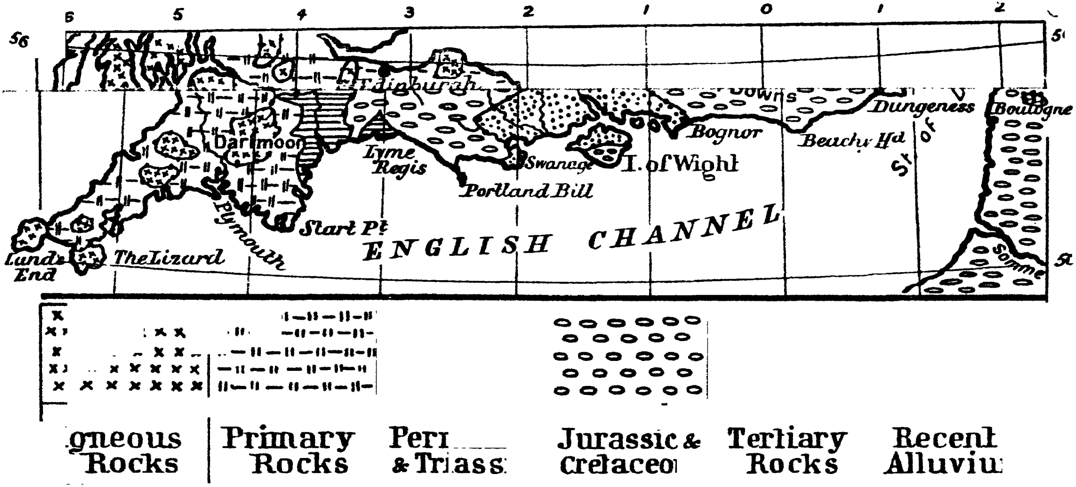
III. Secondary Formations.

(*a*) The upper and lower Chalks give good sheep land, but a great area remains undeveloped. When there is any depth of soil it is of moderate fertility, and is well suited for corn, clover or other leguminous crops. Fairly productive soils derived from the chalk exist in Yorkshire and Lincolnshire (the Wolds), Norfolk, Suffolk, Herts, Essex, Cambridge, Bucks, Oxon, Wiltshire, Hampshire, Dorset, Sussex, Surrey and Kent.

(*b*) The upper Greensand weathers into a very fertile soil, and is improved by admixture with the marls of the lower Chalk.

Good soils are found in Bedfordshire and Kent (fruit and hop district).

(*c*) The lower Greensand is very unproductive, and occurs in Kent, Surrey, Sussex and Devon. It generally forms barren heaths.



IMPORTANT GEOLOGICAL FORMATIONS OF ENGLAND AND WALES.

[*To face page 296.*

(*d*) The Weald clay of Surrey, Kent and Sussex is a fine grained clay, difficult and disappointing to work. Gives good woodland and some pasture.

(*e*) The upper Oolite is chiefly represented by the Kimmeridge clay, which gives the excellent pastures of North Wilts and the vale of Aylesbury. It forms a band of fertile soil from the west of Dorset to the north of Norfolk, and is found in parts of Lincolnshire and Yorkshire (in neighbourhood of Scarborough).

(*f*) The middle Oolite is represented, agriculturally, by the Oxford clay, which blends with the Kimmeridge clay, and has a similar outcrop across the country in a north-west direction. The Oxford clay is, however, "poorer" than the Kimmeridge clay, but fairly fertile tracts are found in Hunts, Beds and Bucks, Oxon and Wilts. As it is expensive to farm as arable land, it is often left as pasture.

(*g*) The lower Oolite rocks weather into several types of soils. The Cornbrash yields good land. The great Oolite and inferior Oolites give light soils suitable for barley or pasture. There is a rich tract of land in Northamptonshire derived from these Oolites. They also form fairly good land in Oxfordshire, Wilts and Somerset (sandy loams). In Gloucestershire they constitute the Cotswold Hills, where the soil is poor and only fit for sheep farming.

(*h*) The Lias formations are represented by dark bluish clays of very good quality. Sometimes, however, they are heavy and rather difficult to work. They are then left for pasture, as in Leicestershire. The Lias clays form fertile districts in Yorkshire, especially in the Cleveland district, Notts, Warwickshire and Worcestershire. In Somerset the land is most fertile. The vales of Gloucester, Evesham, and Berkeley are characteristic examples of Lias clay soils.

(*i*) The Trias formations are also important agriculturally. They form a deep red rich soil in West Leicestershire and Warwickshire, the "Vale of York" and the "Garden of Derbyshire." Excellent land in Worcester, Shropshire, Cheshire and West Lancashire is also of Triassic origin.

Primary Formations.

(*a*) The Magnesian limestone is not important. It is not well represented in England, and only forms poor soils, which are often covered by drift clay (especially in Durham).

(*b*) The Coal Measures consist of alternate beds of hard bluish black clay and silicious sandstone, which invariably yield soils of inferior agricultural quality.

(*c*) The Mountain Limestone forms the greater part of the surface of Northumberland, a considerable part of Durham

West Yorkshire and Derbyshire. Much of it is uncultivated and belongs rather to the picturesque portions of the country than to those devoted to farming.

(*d*) Devonian and Old Red Sandstone soils yield first-rate wheat, hop, and fruit land in Hereford, Devon, Cornwall, Monmouthshire and South Wales.

The "Cornstones" give soils of great fertility, while Upper and Lower Devonian soils are often worthless and barren.

(*e*) Silurian and Cambrian formations frequently yield land of fair quality, but generally in inaccessible positions, such as in the mountainous regions of Wales, the Cumberland Lake District, and the North of Scotland. They are, therefore, of little or no importance to the farmer.

Generally speaking, the hard rocks weather slowly, and therefore stand very high, forming the hills and mountains of the country. This land is not valuable for farming purposes, because of the difficulties of transit as well as the thinness of the soil. Soft rocks are generally low-lying, they weather readily and form deep soils. It should be remembered that the lighter soils are more profitable agriculturally than the heavy clay soils which are fairly common in our country. Where soils derived from two formations are mingled, the land is generally more fertile than where either soil occurs alone. Further, farming operations may greatly improve a soil; thus many of the well-known clays in England, when cultivated form fairly rich corn lands. The seven most important clays are the Lias, Oxford and Kimmeridge clays of the Jurassic series; the Weald and Gault clays of central Sussex and Kent, and the London and Plastic clays of the Tertiary Formations. They have also been referred to above.

SUMMARY.

Soil is the name applied to the more or less powdered matter forming the upper layers of the earth's land surface.

Subsoil differs from soil in texture, colour, composition and character. It is further described in the following chapter, under "The Fertility of the Soil" (which see).

Soils are formed by the decomposition and disintegration of rocks, *i.e.* weathering. The chief agencies are: aqueous, atmospheric, chemical, organic and volcanic.

Minerals are composed of chemical elements and compounds. They are inorganic, but naturally formed.

Minerals form **Rocks**, and Rocks form **Soils.** **Organic matter** sooner or later becomes mixed with the rock soil.

Common Minerals may be classified as:—

(i.) Simple elements, like Graphite and Sulphur.
(ii.) Simple compounds, like Quartz and Pyrites.
(iii.) Complex compounds, like Felspar and Mica.

Common Rocks may be classified as:—

1. *Aqueous*
   - (*a*) Sandy rocks, *e.g.* Gravel, Sandstone.
   - (*b*) Clay rocks, *e.g.* Mud, Shale.
   - (*c*) Chalky rocks, *e.g.* Limestone, Marl.
2. *Igneous*
   - (*d*) Crystalline rocks, *e.g.* Granite, Syenite.

All rocks, whether (soft) Aqueous or (hard) Igneous, produce characteristic soils, but many of the ingredients may be washed away and deposited elsewhere.

A Geological map to be of use to the farmer must show Alluvial and Drift deposits. The Stratified formations, where not so masked, form characteristic soils. The student should mark the position of the most important of these on a blank map of England and Wales.

* * *

CHAPTER XXV.*

The Composition and Character of Soils.

Soils may be considered under the following heads, viz. :—

I. Their chemical composition.
II. Their physical character and properties.
III. Their productive powers.

1. **Chemical Composition.**—The chemical composition of soils varies, not only because they are formed from different rocks, but because of the further effects of weathering, agricultural operations, and the admixture of organic or vegetable matter. The following substances are found in varying proportions in all fertile soils:—

Organic matter.
Silicious matter.
Alumina.
Lime.

Potash and Soda.
Oxide of Iron.
Phosphoric Acid
Sulphuric Acid
Hydrochloric Acid
Carbonic and Nitric Acids
} In chemical combination.

We shall consider these again when we deal with plant food present in the soil, the amount of which is not indicated by a chemical analysis of the soil as a whole. The most variable of the above substances is the organic matter, which varies from two per cent. in poor sandy soils to ninety-eight per cent. in

---

*In this and the following chapters "Plant Food" is used in the sense of "*raw food material*" derived from the soil in order to be elaborated by the plant into its true food.

some peats. Too much importance cannot be given to the proportion of organic matter present: this will become evident as we proceed.

The amount of silicious and chalky matter also varies from one to ninety per cent. For the silicious matter to be of any value it must exist in a soluble form, in which condition it is always found in a fertile soil.

A short study of the important table below, giving the chemical composition of typical soils, will at once show how greatly the proportion of the different constituents varies.

TABLE I.

Percentage Composition of Soils.

	A. Poor Sandy Soil.	B. Fertile Loam.	C. Fertile Clay.	D. Poor Peat Soil.
Organic Matter	1·06	6·36	7·06	87·97
Silicious Matter	96·30 (All insol.)	78·24 (3% sol.)	60·23 (Trace sol.)	10·02 (Varies greatly).
Alumina and Oxide of Iron	1·82	7·07	17·65	·53
Lime and Magnesia ..	·30	3·63	8·42	·62
Potash and Soda	·30	2·42	4·42	·29
Salts of:— Phosphoric Acid. Sulphuric Acid. Hydrochloric Acid. Carbonic Acid. Nitric Acid.	·22	2·28	2·22	·57
	100·00	100·00	100·00	100·00

It is interesting to compare these figures with the percentage chemical composition of a typical rock. The following table (II.) gives at a glance the chemical constitution of ordinary granite, while Table III. gives its percentage composition, also that of syenite rock. (*See page* 302.)

These rocks weather into fertile soils fairly well represented by the soils *B* and *C* dealt with in Table I. The student should compare the percentage compositions. Of course, it must be borne in mind that the soil will always differ more or less from the rock in composition because, as we have already seen, in the process of weathering the more soluble constituents of the rock will be dissolved away, and the finer matter, like the alumina, will be transported mechanically, so that the soil remaining will show a lower percentage of soluble salts and

TABLE II.

Composition of Granite.

ELEMENTS.	COMPOUNDS.	MINERALS.	ROCK.
Silicon (Si) Oxygen (O)	Silica (SiO_2)	Quartz	Granite.
Silicon (Si) Oxygen (O)	Silica (SiO_2)	Felspars	
Aluminium (Al) Oxygen (O)	Alumina (Al_2O_3)		
Potassium (K) Oxygen (O)	Potash (K_2O)		
Calcium (Ca) Oxygen (O)	Lime (CaO)		
Silicon (Si) Oxygen (O)	Silica (SiO_2)	Micas	
Aluminium (Al) Oxygen (O)	Alumina (Al_2O_3)		
Magnesium (Mg) Oxygen (O)	Magnesia (MgO)		
Potassium (K) Oxygen (O)	Potash (K_2O)		
Iron (Fe) Oxygen (O)	Iron Oxides (FeO and Fe_2O_3)		

TABLE III.

Percentage Chemical Composition of Granite and Syenite.

	GRANITE.	SYENITE.
Silica	72·0	59·3
Alumina and Oxide of Iron	17·5	23·2
Lime and Magnesia	2·1	9·6
Potash and Soda	8·4	7·9
	100·0	100·0

other substances. The presence of vegetable matter in a soil will also indicate that some soluble portions of the soil have been withdrawn as plant food. The insoluble matter, however, is always being acted upon by weathering processes similar to those which pulverise the rocks. Cultivation of the soil assists greatly in this action by exposing it to the air and rendering soluble the insoluble matter, which thus becomes available for plant food.

Humus.—This is the name given to the decomposing vegetable matter present in the soil. It plays an important part in the formation or production of plant food.

Plate XVIII.—BEECHES WITH THEIR CHARACTERISTIC LACK OF UNDERGROWTH.

The organic matter present in the soil varies greatly in amount, but it is very rarely absent in a fertile soil and in peat it often composes the entire mass. It is the humus which imparts to the soil, especially in the case of loams, its dark brown colour; in fact, the two chief pigments are:—

(i.) The humus, or organic matter.

(ii.) The compounds of iron present.

Humus may be described as a dark brown, soft, porous substance, consisting chemically of (*a*) organic acids, like ulmic, geic and humic acids, which readily decompose into carbonic acid, and of (*b*) ammonia, water and nitric acid. It is seen in the state of greatest purity in well-rotted leaf mould. Its value in the soil must not be overlooked, although some regard its presence as an effect rather than a cause of fertility. A rich soil suitable for the growth of plants cannot fail to accumulate vegetable matter. On the other hand, many soils nearly devoid of humus are comparatively fertile, for example: those formed from the weathering of lava formations and volcanic dust. It is a well-known fact that land adapted for the growth of timber will yield many tons per acre of wood for a number of years, after which the soil will be much richer in organic matter than it was before. One will remember the thick carpet of decaying leaves which replaces the undergrowth in a beech wood. Both here and later on, when dealing with the fertility of the soil, we shall find that we must not regard the soil as a mere mass of powdered rock, but as a complex mixture of inorganic and organic matter, the result or product of various forces and conditions largely modified, and in many cases induced, by the presence of animal and plant life. Frequently soils, too, are veritable "graveyards of countless generations of animated nature."

THE AMOUNT OF ORGANIC AND INORGANIC MATTER PRESENT.—This may be ascertained by the careful burning of a known quantity of dry soil in a crucible. In this simple chemical experiment, the organic part is burned away and the inorganic part remains as the ash.

The following percentage results are obtained for typical soils:

	ASH : INORGANIC.	ORGANIC MATTER
Fertile Soil: Loam or Clay	93—97%	7—3%
Soil of Intermediate Fertility ..	98—99·5%	2—·5%
Poor Soils	99·5—100°/o	·5—0%

In cultivation, the soil should be thoroughly exposed to the air so that any organic matter present may be oxidised, with the formation of carbonic acid gas. Nitric acid is also formed from the humus, perhaps not directly by a chemical oxidation, but most probably by the action of the nitrifying bacteria or germs, which convert the nitrogen present, first into ammonia and then into nitric acid. These bacteria, which are present in enormous numbers in fertile soils, set up under favourable conditions what may be regarded as a kind of fermentation which leads to the formation of plant food. Probably, acids are formed which combine with the bases present in the soil, the nitric acid produced giving the valuable nitrates, which are immediately available because of their marked solubility. The three conditions which favour this fermentative and nitrifying process are:—

(i.) A suitable temperature.
(ii.) Abundance of air.
(iii.) Abundance of moisture.

Want of exposure of the soil to the air leads to the *partial* decomposition of the humus or vegetable matter, and to the formation of various injurious and organic acids which remain uncombined and unneutralised, and thus give a characteristic and deplorable sourness to the land.

2. **The Physical Character of Soils.**—Here we shall consider the character of soils generally, as depending upon particular properties, which will be dealt with later.

Most soils consist largely of sand and clay, and as these substances differ much in physical properties, we shall expect to find corresponding differences in the character of any soil according to the proportion of sand and clay present. The evident properties of sand and clay are set out in the following table, and these characteristics are naturally transmitted to the soil in which one or the other predominates.

SAND.	CLAY.
1. Little adhesion.	1. Much adhesion.
2. Cannot be moulded.	2. Can easily be moulded.
3. Firm, hard and gritty to touch.	3. Soft and plastic to touch.
4. Holds little or no water.	4. Holds much water.
5. Little power of holding fertilisers.	5. Much power of holding fertilisers.
6. Composed of insoluble silica.	6. Contain double silicates, which yield soluble silica.
7. When dry, does not crack.	7. When dry, cracks and injures roots.
8. "Light" and easy to work with horse labour.	8. "Heavy" and expensive to work.

KINDS OF SOILS:—

(i.) *Sandy Soils* have a loose open nature, which enables the plant to send its roots easily in search of food. As there is little adhesion, they are said to be "light" soils and easy to work. Sandy soils, however, have little power of holding fertilising matter, so that their cultivation is often disappointing, as even when manure is applied they do not fix or retain the plant food readily. Sand itself cannot become a plant food, as it is altogether insoluble, and by the majority of plants it is not required. Corn crops obtain their silica almost solely through the agency of the double silicates, which are altogether wanting in sandy soils.

(ii.) *Clay Soils* are, as a rule, more fertile than sandy soils. For one reason, they are rich in double silicates. These important double silicates of alumina consist of silica combined with alumina, and some other base, like soda, potash, lime or ammonia. Clays have the power, too, of holding both mechanically and chemically the fertilising constituents of manure. Being of a plastic sticky nature they are difficult to work, and are often spoken of as "heavy soils" because of this. It is interesting to note, however, that bulk for bulk clay is lighter than sand. Since clay soils tend to hold water, they always require thorough drainage.

(iii.) *Calcareous Soils* are those which contain much chalk or lime. They are found in the Cretaceous, Oolitic and other Limestone areas of England, and are generally light in colour, dry and warm, and capable of producing good root crops when there is sufficient soil, or of forming excellent pasture land.

(iv.) *Loams.*—This name is applied rather loosely to soils, which possess about equal quantities of sand and clay. Lime is often present also, and when it is so to any great extent, the soil is known as a Calcareous Loam. The organic matter present imparts a characteristic dark colour to the soil. Loams are generally fertile, and under a good system of cultivation, are suitable for almost any kind of plant life.

MECHANICAL ANALYSIS.—It is an advantage sometimes to ascertain the relative proportions of sand and clay in a given soil. While the chemical analysis of a soil presents the greatest difficulty to the average student and requires a thorough knowledge of chemistry, a mechanical analysis may easily be carried out. It depends upon the fact that when a soil is well shaken up with water, the clay, because of the fineness and lightness of its particles, will remain longer in suspension than the sand.

The given soil, from which all large stones have been removed, is therefore shaken up with water, and the muddy water decanted to another vessel and allowed to settle. By continuing this process once or twice the sand and clay may easily be separated. The clear water can be poured away (or if it remains cloudy it can be filtered), and after boiling off the remaining water and drying the residue, the relative amounts of sand and clay may be roughly ascertained by weighing. From the results of similar experiment, soils have been classified as follows:—

	Percentage of Sand.	Percentage of Clay.
Sandy Soil	80—100	20— 0
Sandy Loam	60— 80	40—20
Loam	40— 60	60—40
Clay Loam	20— 40	80—60
Clay Soil	0— 20	100—80

These numbers may easily be remembered. Let us enquire what crops are best suited to the different kinds of soils?

(i.) "Light" soils are best suited for the growth of barley, turnips, green crops and rye.

(ii.) "Heavy" soils for crops of wheat, beans, swedes and mangolds.

(iii.) Calcareous soils for the growth of clover, peas and beans.

(iv.) Loams, for almost any crop.

(v.) Peaty soils favour the growth of oats, rape, and potatoes.

Lime and Liming.—We have already seen that lime is an important constituent of the soil, and it is an ingredient of all cultivated plants. The high proportion of lime which occurs in the ash of many plants to a certain extent indicates its importance as a plant food, while there can be no doubt as to the great benefit which the land derives from its application —a process which is called liming.

Lime is applied in two conditions:—(i.) *raw*, in the form of chalk or marl; (ii.) *prepared*, when it is prepared by burning oolitic, magnesian, mountain, or ordinary limestone. The effect of heat upon these limestones is to drive off carbon dioxide and to leave the limestone in a highly porous, caustic and active state.

As lime is constantly being withdrawn and washed out of the soil, it often requires renewal. It has been estimated that twenty tons of turnips will carry off 120lbs. of lime, two tons of clover, about 80lbs., and twenty-five bushels of wheat 12½lbs., on an average for farm crops, of over 200lbs. per acre.

In a garden lime should be administered every three years; on farm lands about every eight or nine years, according to the nature of the soil and the crops grown.

It is especially beneficial in three cases :—

(i.) When the soil is deficient of it.

(ii.) In the farming of "heavy" clays.

(iii.) In order to sweeten "sour" land, or to improve peaty soils generally.

In practice the prepared (or burnt) lime gives the best result. It is applied in what are called "dressings" of three, six or nine tons per acre, according as the soil is light, intermediate, or heavy. In the garden it is generally applied in the winter time, in the slaked condition, or as a fine powder. The careless scattering of coarse lumps is not so efficaceous, and is to be deprecated. Half a pound to the square yard is the outside limit; if this is exceeded, plant life is often injured. If possible, it is always best to apply the dressing when the ground is bare. Gas lime is sometimes substituted, but it should be used with caution, owing to its admixture with compounds poisonous, or at least harmful to plant life.

In this connection the student may be asked the following questions:

Why are our gardens and fields infested with harmful insects and grubs?

Why do our vegetables, especially the peas, lose their bright green leaf?

Why is the application of other manures ineffectual and disappointing?

In brief, it is because we are apt to overlook the necessity of liming or marling.

Let us summarise the use of lime on the soil :—

(*a*) It combines with organic and other acids and sweetens "sour" land.

(*b*) It acts in combination, as an important plant food.

(*c*) It decomposes the double silicates of the soil and sets free the alkalies, potash and soda for plant food, and thus renders dormant matter active.

(*d*) The use of lime is favourable to the production of nitrates, especially nitrate of potash. It also reacts on farmyard manure in this direction.

(*e*) It improves the texture of the soil by making it more porous and allowing the free passage of air.

(*f*) It destroys harmful insects and grubs and lessens the possibility of disease.

(*g*) It improves the absorbing powers of some soils and is used with advantage to this end on light, unfertile, sandy soils.

3. The Physical Properties of Soils.—These are as follows:—

(i.) Porosity, and the power of absorbing water and gases.
(ii.) Capillarity, which depends almost entirely on its porosity.
(iii.) Power of retaining fertilising matters and plant food.
(iv.) Thermal properties, as shown by the temperature of the soil, under varying conditions.
(v.) Drying or evaporation power.
(vi.) The density of the soil.

We will consider each of these briefly.

(i.) POROSITY OF THE SOIL.—This may be measured by the fineness of the particles; thus a coarse sand is less porous than a finely-grained clay or any powdery soil. It is owing to this porosity that the soil can retain sufficient moisture for the vegetation growing upon it. It enables the soil to furnish the plant with food during dry periods. By experiment it may be proved that during twelve hours of night:

1000 lbs. of	Sand	absorb	about	2	lbs.	of	water.
,, ,, ,,	Sandy soil	,,	,,	10	,,	,,	,,
,, ,, ,,	Loamy soil	,,	,,	20	,,	,,	,,
,, ,, ,,	Clay soil	,,	,,	30	,,	,,	,,
,, ,, ,,	Peat soil	,,	,,	40	,,	,,	,,

The more vegetable matter present the greater its porosity and absorbing power. We shall further see, under Section 3 below, that by this property, assisted by others, soils are enabled to retain the fertilising matters of manures, with sufficient tenacity to overcome the tendency of rain water to wash them out of the soil. The fertility of well-drained clay soils is largely due to their high degree of porosity. Looking at the question in a more practical way, a sandy soil for which thirty shillings per acre was paid absorbed during the twelve night hours about 10 lbs. of water per 1000 lbs., while a soil for which forty-four shillings per acre was paid absorbed 15 lbs. of water per 1000 lbs. The latter land was correspondingly fertile. Of course it will be understood that other properties, conditions and characters help to determine the fertility; these will be dealt with later.

(ii.) CAPILLARITY OF THE SOIL.—This phenomenon has already been explained. We have seen that the water rises from the saucer, up through the mould in the flower-pot to the roots of the plant, like tea rises in a lump of sugar. The same action takes place in the soil, and from what has been said above, the amount of capillarity depends upon the natural porosity of the soil. It is low in sandy soils and high in clays, loams and peaty soils, for the effect of the force varies directly as the number and inversely as the size of the pores. Interesting experiments may be carried out by filling glass tubes with different kinds of soil in various conditions of fineness. A column of finely-divided clay will become wet 37 inches above the level of the water in which it is dipped. If the clay is replaced by sand the water rises to 23·7 inches. Loams will carry up the water to nearly the same height as the clay—in the one examined in this experiment, to 34·5 inches. If coarse fragments, stones, etc., are introduced into the tubes the soils become wet only to a height of nine or ten inches. While this property tends generally to enhance the fertility of the soil, by keeping it moist, in some cases the action produces injurious results by bringing up sour and harmful matters from the subsoil.

(iii.) POWER OF ABSORBING AND HOLDING FERTILISING MATTER.—This property is partly mechanical and partly chemical. It may be easily demonstrated that watery solutions of ammonia, potash or soda, salts and soluble phosphates, after passing through ordinary soils are robbed of almost the whole of these substances, which are known to be most important plant foods. They are held back by a kind of physico-chemical process, and are retained even after the soil is "washed" two or three times with water. It is found that liquid manure which is often of a dark brown colour when it filters through the soil, reaches the subsoil almost entirely decolorised and purified—a fact which is made use of in sewage farming. The soil thus seems to have an affinity for certain salts— the essence of fertilising agents—and to fix and retain them until they are required by the plant.

(iv.) THERMAL PROPERTIES.—The warmth of the soil is an important factor in its fertility. The student will remember that plant growth is much influenced by the temperature of the soil. Soils vary greatly in their powers to absorb and retain heat. These properties depend upon :—

(*a*) The colour of the soil.

(*b*) Its heat capacity.

(*c*) Its conductivity.

From this it will be seen how it is that all kinds of land are not raised to the same temperature when exposed for a given length of time to the same amount of heat or sunshine. Generally speaking, the darker the colour of the soil the warmer it will be, because it absorbs more heat than a light-coloured soil, which reflects it. But the soil's heat capacity chiefly depends upon its constituents. Sandy soils are warm, while clayey soils are often cold, irrespective of their colour. In the latter case the sun's heat is used to warm and evaporate the water, which is held by virtue of the porosity of the clay. It must be remembered that the heat capacity of a soil—that is, its power for *absorbing* heat—is profoundly modified by its power of retaining heat; this is greatest in sands and least in organic soils. Can you devise a simple method for comparing the heat-absorbing and heat-retaining powers of any given soil, and also its conductivity for heat?

(v.) EVAPORATION POWER.—The water held by some soils passes off into the air far more rapidly than in others. This has important bearings on the temperature of the soil. Sands not only possess little capillary and absorbing power, but as soon as they become moist they tend to become dry again quickly, by evaporation. Hence, as we have seen, sands form warm dry soils and the vegetation growing on them is soon burned up in hot, dry seasons. On the other hand, in a rainy district the sandy soil produces luxuriant vegetation. Clays make the best use of little moisture, but often where heavy rains are frequent they become cold and waterlogged, and the plant-life is consequently poor because of the excess of moisture, which, among other things, interferes with respiration in the plant tissues.

(vi.) DENSITY OF THE SOIL.—This depends upon the density or relative weight of its constituents—chiefly upon the proportion of sand and clay present. The student must remember that the terms "light" and "heavy" as applied to soils have no reference to their actual density or weight, for a "heavy clay" is bulk for bulk lighter than a "light sandy soil." The terms refer to the ease or difficulty they offer in cultivation.

At first sight the weight of a soil seems quite unimportant, but it is often necessary to take it into account when calculating the amount of any constituent in a given area.

The presence of stones will, of course, affect the density, and when they exist on the surface of the soil they modify its properties to a certain extent by preventing evaporation and the radiation of heat. There is, however, some diversity of opinion as to whether the presence of stones tends to make the soil warmer. Stones break the force of the wind, some may be regarded as continually yielding new soil under the action of the various disintegrating agencies; they certainly aid in the passage of water through the soil, and in many cases make an otherwise heavy land cheaper to work, so that it is generally agreed that by removing the stones from the land (except perhaps in flinty districts) its value is diminished from an agricultural standpoint.

4. **Fertility of the Soil.**—A complete chemical analysis of the soil shows that there is a large surplus of plant food present—sufficient in many cases for hundreds of crops. Yet in practice, unless the soil is enriched with manure every year the yield almost immediately falls off. Why is this? It is because of the great difference between the total plant food and the total *available* plant food present in the soil. On this point the farmer and the chemist have often been brought into antagonism. The chemist's results of so much silica, lime, potash, etc., are almost useless, unless he states what percentage of them is in a soluble condition. A far simpler analysis is of the greatest service to the farmer, and this aims at finding the amount of available plant food present which is soluble in the soil water or in the weak acid sap which has come out from the root hairs. If a known weight of dried soil is taken and well shaken up with boiling rain water the amount of soluble matter may be ascertained by filtering off the undissolved matter and slowly evaporating the watery filtrate to dryness in a steam oven. If the weight of the evaporating dish is known, the amount of residue can be easily calculated and compared with the weight of the dry soil taken.

This soluble portion of the soil is the useful active matter, and largely represents the available plant food. The insoluble matter which remains on the filter paper is the dormant, reserve matter of the soil, much of which in the course of time would have become transformed into the active soluble condition. Professor Bottomley, of King's College, has pointed out recently that a soil at Rothamsted, which contained theoretically enough phosphoric acid to supply a wheat crop for 300 years, had only sufficient available for seven years. Thus plant food material is sometimes said to exist in two states or stages in the soil:—

(i.) That in which it is ready to enter the plant, and

(ii.) That in which it will only become slowly available for plant food.

A chemical analysis of the residue obtained above, would show that the plant food in the soil consists of potash, soda, lime and magnesia in combination with nitric and phosphoric acids, and to a lesser extent with humic and other organic acids, together with the *sulphates* of sodium, magnesium and calcium and the *chlorides* of potassium, magnesium and calcium.

We shall refer to these again in greater detail when we deal with plant food, but the student should remember the caution already given, not to regard the soil only as an aggregation of dead chemical compounds. Comparatively recent revelations tend to show that the soil is alive, and in cultivation must be treated with that care and thoughtfulness which the proper and profitable management of the farm live stock demands. We have seen that roots feed on dissolved mineral substances, but it is not so obvious that the soil is the home of countless living workers (bacteria), whose labours profoundly modify the mere processes of solution and diffusion as we understand such terms in our school laboratories. Some of the more important soil bacteria have been isolated, and the manufacture and absorption of the food by their action in the soil has been and is still being investigated. Many authorities in scientific agriculture recommend the inoculation of the soil with these bacteria in the case of leguminous crops. It must be remembered, however, that the bacterial cultures are not a manure, but that they simply increase the power of fixing the nitrogen of the ground air.

Although inoculation is not a panacea for all soil ills, there is no doubt that it is efficacious in the crops referred to, the tubercles on the roots of which are teeming with millions of these nitrifying bacteria.

CONDITIONS OF FERTILITY.—Let us now consider some of the most important conditions of fertility.

(i.) Plant food must be present in the active condition and in the proportion required by the plant. That food required by the plant in question which is present in the least proportion determines the current fertility of the soil.

For example, if a plant requires twenty parts of lime and only ten parts are present in the available condition, no matter how abundant the other substances are, without liming the plant cannot come to maturity and the crop will fail.

(ii.) The soil must have a good retaining or fixing power, so that the fertilising constituents of manure may be held until required by the plant. This has already been shown to depend not only upon the physical properties but largely upon the chemical character of the soil. It will be remembered that the double silicates of clays and loams are especially concerned in retaining plant food, and what is most important, the ammoniacal compounds of manures.

(iii.) The soil must possess good solvent powers and offer a free passage for water and air either naturally or artificially (by drainage).

(iv.) There must be sufficient depth of earth in order that the root may descend with ease in "search" of food. It is interesting in this connection to notice the *extreme* depth of the roots of farm crops:—

Cabbage and Turnip	..	Longest	Roots	8 feet.
Perennial Grasses	..	,,	,,	4 feet.
Wheat	..	,,	,,	9 feet.
Lucerne	..	,,	,,	10 feet.
Parsnip	..	,,	,,	13 feet.

The above figures are given on the authority of Professor Muir of Yorkshire College, who also quotes M'Alpine (Transactions Highland Agricultural Society 5th Series, Vol. II)

N.B.—The importance of a deep soil and a good subsoil is evident.

(v.) To a great extent the character and composition of the subsoil and underlying rock is also an important factor in determining the fertility of the surface soil. It will repay us here to consider in further detail what is meant by the term "subsoil."

This word SUBSOIL is used to express the stratum which underlies the superficial earthy covering, irrespective of its depth beneath the surface. The agricultural use of the word differs somewhat from its geological use. In the former case—which is the more important to us—it is regarded as that section or zone immediately under that cultivated.

A soil may be well stocked with plant food and be of good physical character, but to be productive it must have a proper subsoil.

Upon the subsoil depends the drainage of the surface soil. A light sandy or gravelly subsoil secures the natural drainage of the surface, although, it has already been pointed out, that it is likely to lead to drought and failure in dry weather. Sometimes a solid rock forms the subsoil. If it is a dry rock like chalk, it will give a dry soil, while an impermeable clay will have an opposite effect. With a rocky subsoil there is generally a thin soil and low standard of fertility. Subsoiling is the name applied to the breaking up of the soil immediately below that which is normally cultivated. It often happens that hard layers of earth have been formed which seriously interfere with the cultivation of the soil in farming operations generally. These hard bands are known as pans. They are produced in a variety of ways:—

(*a*) *The Plough Pan* is formed by the passage of the plough and treading of the horses, when the soil is cultivated year after year to the same depth. It is, of course, cured by deeper cultivation.

(*b*) *The Moor, or Iron Pan* is formed by an ochreous deposit which resists the ordinary operation of ploughing and requires to be broken up by a strong subsoiler and six horses. It consists largely of an accumulation of iron compounds, chiefly the oxides of iron.

(*c*) *The Lime Pan.*—It is a well-known fact that lime tends to sink through the land, and owing to frequent liming it further tends to accumulate. Shallow cultivation, again, favours the formation of a lime pan. It may be fairly easily broken up, and when mixed with the surface soil, the latter is much improved. This also immediately improves the drainage.

Good cultivation not only improves the soil but also the subsoil, both chemically and physically. The most stubborn subsoil will yield before—

(*a*) Liberal manuring;
(*b*) Good drainage;
(*c*) Access of air;
(*d*) Deep cultivation.

The admission of water and air leads to a natural sweetening of the subsoil, and a change in its colour is an outward sign that the processes of oxidation and the complete decay of any organic matter present are preparing fresh stores of wholesome plant food. With this improvement, the roots of the plants pass further downwards and the crops are greatly benefited.

We have referred above to subsoils which exert an injurious effect on the surface soil by the formation of pans. There are, however, subsoils which exert an exceptionally beneficial effect upon the surface soil. A light-topped soil resting upon a retentive subsoil is regarded as a happy combination, while a clay situated upon a sand or gravel, if not of too loose a character, is considered an ideal arrangement, for the sandy subsoil naturally drains the clay. We have said that it is a distinct advantage in many cases to mix the surface soil with some of the subsoil and to occasionally adopt deep cultivation, but care must always be taken in deepening any soil that injurious matters are not brought up from below, especially at the wrong time of the year.

(vi.) It is obvious that climate greatly influences the fertility. A soil may contain all the substances required by the plant or crop in the proper proportion, yet if it is adversely situated as regards climate, winds, rainfall, altitude, etc., one's efforts will be thrown away.

(vii.) The geological position of a soil also, to a certain extent, may limit its fertility. It has already been pointed out that where there is an outcrop of two or three different formations in proximity, the soils may mutually benefit one another by admixture. One formation will often act as a kind of natural fertiliser to another. This especially applies to the land in the neighbourhood of the great chalk and limestone formations.

(viii.) Absence of injurious weeds tends to increase the fertility. We give here a few weeds characteristic of different kinds of soils.

- (*a*) On grass lands, generally in large quantities: common daisy, foxglove and rest-harrow.
- (*b*) On limey soils, generally less plentiful: knapweed, burnet and wild pansy.
- (*c*) On loams, weeds of a strong tenacious nature: chickweed, speedwell and groundsel.
- (*d*) On sandy soils, abundant, but weak and less tenacious: poppy, cornflower, and bracken.
- (*e*) On clays, comparatively few weeds: coltsfoot.

(ix.) Finally, there must be nothing injurious to plant life in the soil, nor must anything be added by young, inexperienced, "scientific" farmers by way of experiment, under the comprehensive term "manuring." If it is desired to experiment it must be done with due care. It is best to select a small parcel of ground and mark it off into so many equal portions. On these experimental plots the actual needs of any particular crop may be investigated by treating the growing plants with nitrates, phosphates, and potash, alone or in combination.

The individual plots should not be smaller than twenty square yards—larger if possible. The resulting plants should always be weighed under similar conditions, as mere appearances are often deceiving. Thus, if there were eight small plots they might be treated as follows:

Plot.
1. No manure.
2. Sulphate of potash.
3. Superphosphates.
4. Nitrate of soda.
5. Potash (2) and Phosphate (3).
6. Nitrate (4) and Phosphate (3).
7. Potash (2) and Nitrate (4).
8. All three—Potash, Phosphate and Nitrate.

The use of these substances will be explained in the next chapter. If other similar plots are available the times of application may also be varied, as also the amounts used; in fact, many interesting combinations of conditions may be experimentally made with most gratifying results.

SUMMARY.

1. Chemical Composition of Soils.

A. Organic Matter, Silica, Alumina, Lime, Magnesia, Potash and Soda, Oxide of Iron.

B. Phosphoric, Sulphuric, Hydrochloric Nitric and Carbonic Acids in chemical combination with the substances under *A* above. The amounts vary greatly in different soils.

HUMUS is the name given to the decomposing vegetable matter present in the soil.

The amount of *Organic* and *Inorganic* matter in the soil may be ascertained by burning a known weight.

NITRATES are formed in the soil by bacterial action, which depends upon—

(i.) Suitable temperature;
(ii.) Abundance of air and water.

2. Physical Character of Soils.—This is largely determined by the relative amounts of sand and clay present

Physically, soils are classified as—(i.) Sands, (ii.) Clays, (iii.) Calcareous Soils, and (iv.) Loams.

A MECHANICAL ANALYSIS of the soil may be made by separating the clay and sand by decantation.

LIMING is especially useful in three cases:—

(i.) When the soil is deficient of it.
(ii.) In farming a heavy clay.
(iii.) To sweeten "sour" land.

USE OF LIME IN THE SOIL:—

(*a*) It combines with free acids.
(*b*) Forms plant food.
(*c*) Decomposes the double silicates.
(*d*) Favours formation of nitrates.
(*e*) Improves texture of the soil.
(*f*) Destroys harmful insects.
(*g*) Improves the absorbing powers of soil.

3. **The Physical Properties of Soils** are porosity, capillarity, power of retaining plant food, thermal properties, drying and evaporation power, density.

4. **The Fertility of the Soil.**—Plant food is either Active or Dormant.

The *active*, available plant food consists of—

(i.) Potash, Soda, Lime, Magnesia in combination with Nitric, Carbonic and Phosphoric Acids.
(ii.) Sulphates of Sodium, Magnesium and Calcium.
(iii.) Chlorides of Potassium, Magnesium and Calcium.

CONDITIONS OF FERTILITY are:—

(i.) Available plant food must be present.
(ii.) A good retaining and fixing power for plant food.
(iii.) Good solvent powers with adequate drainage.
(iv.) Sufficient depth of earth.
(v.) A good subsoil and absence of "pans."
(vi.) A suitable position and climate.
(vii.) Geological considerations.
(viii.) Absence of injurious weeds.
(ix.) Absence of injurious matters.

THE SUBSOIL may be improved by—(i.) deep cultivation, (ii.) good drainage, (iii.) access of air, (iv.) liberal manuring.

The use of *Experimental Plots* is strongly advised.

CHAPTER XXVI.

Plant Food Supplied by the Soil.

1. **Constituents of Plants.**—In common with all living things, plants are composed of organic and inorganic matter. The organic constituents make up ninety-five or ninety-six per cent. of the plant, while the inorganic matter present varies greatly in different parts of the plant, the average being four or five per cent. If seeds are burnt the ash which represents the inorganic part of the plant amounts only to two per cent., but in the case of the leaves from twelve to fifteen per cent.

The organic matter consists of:—

Protoplasm (in the living plant).
Woody fibre and cellulose.
Starch, sugar, gum and resin.
Vegetable albumin, glutin, globulin and legumin.
Oils and fats.

The inorganic matters consists of the following, generally in a state of combination with one another.

Silica, lime, potash, soda, ammonia and magnesia.
Hydrochloric, phosphoric, carbonic and sulphuric acids.
Oxide of iron.

Traces of other chemical compounds are often present, but they may be regarded as accidental ingredients.

The organic constituents of plants are composed of the elements—carbon, hydrogen, oxygen, nitrogen, sulphur and traces of phosphorus. Those which contain nitrogen are termed nitrogenous, while those which consist only of carbon, hydrogen and oxygen are non-nitrogenous; vegetable albumin, glutin, globulin, and legumin are examples of the former class, while starch, sugar, and gum represent the latter class. The percentage of any one of these chemical elements varies in different plants, and in different parts of the same plant. For example: 1000lbs. of dried wheat contains 461lbs. of carbon, 434lbs. of oxygen, 58lbs. of hydrogen, 23lbs. of nitrogen, and 24lbs. of ash; whilst 1000lbs. of wheat straw would contain 484lbs. of carbon, 390lbs. of oxygen, 53lbs. of hydrogen, 3lbs. of nitrogen and 70lbs. of ash.

We will briefly describe the NITROGENOUS organic constituents:—

VEGETABLE ALBUMIN, which closely resembles egg albumin, is met with in all parts of the plant, but chiefly in the roots and seeds.

GLUTIN is a thick sticky substance which may be obtained by washing the starch from flour. It is similar in properties and constitution to fibrin in the animal body, and is found in the seeds of wheat, barley and other cereals.

GLOBULIN frequently gives rise to albumin, and is largely found in seeds.

LEGUMIN resembles casein found in cheese. It exists in the seeds of leguminous plants like peas and beans.

The NON-NITROGENOUS organic compounds which make up the greatest part of the plant may be briefly described as follow:—

WOODY FIBRE is the chief constituent of the hard parts of plants, such as stems, branches, veins of leaves, husks of seeds and stones of fruits.

CELLULOSE is closely allied in composition to woody fibre, into which much of it is transformed as the plant matures. Cellulose is found in the wall of the cell and, perhaps, in its purest form in cotton "wool" and stone of the date.

STARCH, one of the most important bodies in plant life, has already received sufficient attention (see Chapter xiv.).

GUMS AND RESINS are found in the fruits, flowers and stems of plants. Waxes, which are closely allied to them, often exist in the form of bloom on fruits, flowers and leaves.

The amount of inorganic matter present in plants may be ascertained by carefully burning a known weight of selected plants. The inorganic salts remain as the ash.

2. **Plant Ash Fallacies.**—At one time it was thought that a chemical analysis of this inorganic ash would indicate definitely the food required by the particular plant under examination. Prof. Wolff has given elaborate tables showing the composition of hundreds of different plants, and much use has been made of these to endeavour to deduce the exact requirements of the plants. But the exhaustive study of the food and manurial requirements of plants during the last

twenty-five years has abundantly shown that the real needs of a plant under ordinary conditions are greatly at variance with those deduced from the analysis of its ash. It has already been pointed out that a careful series of experiments performed on trial plots are far more valuable to the student-gardener or farmer than many detailed analyses. With an average amount of care he may learn experimentally a great deal concerning the demands of plants upon the soil and the judicious use of manure, as well as the effects of different plant foods. Of course there is an evident advantage if he can bring to bear upon his practice a knowledge of chemistry. Thus, of recent years, much has been learned about plant requirements by the study of what are known as water cultures.

3. **Water Cultures.**—Earlier work in this book, in connection with the "selective" action of roots, has shown us that during a plant's first stages of growth many minerals are absorbed, not because they are essential, but merely by virtue of their solubility. This alone should prevent us regarding as vitally necessary *all* the chemical substances found on an ash analysis, for to a certain extent the roots may be compelled to absorb what is given them in the form of manures. Further, the soil, climate and season will naturally modify the processes of absorption.

On the other hand, we can by means of water cultures accurately discover what are really essential mineral substances for plant life, and, further, can trace the effect of removal of any one or more constituent of this mineral food—or, more correctly speaking, raw food materials.

By experiment it has been found that very many plants will grow vigorously and will produce in succession leaves, flowers and fruits if their roots be immersed in the following dilute nutritive solution:—

CULTURE FLUID.

1	Gramme	Potassium Nitrate.
·5	,,	Sodium Chloride.
·5	,,	Calcium Sulphate.
·5	,,	Magnesium Sulphate.
·5	,,	Calcium Phosphate.

A few drops of Iron Chloride Solution.

The above should be dissolved in a litre of distilled water and well boiled for half-an-hour. The liquid is then made up to a litre by the addition of distilled water, and is allowed to cool in a vessel, the mouth of which is closed with a cotton wool plug to prevent the entrance of minute vegetable growths.

Large wide-mouthed vessels are chosen for this experiment, and it is imperative that they should be scrupulously clean. This is best secured by rinsing them successively with tap water, dilute nitric acid and distilled water.

Each vessel is fitted with a cork pierced by two holes:—

(i.) For the admission of the roots of the plant so that they may be in the culture fluid, which must three-parts fill the vessel.

(ii.) For the entrance of air, which has already been seen to be necessary for the plant's well being.

On fitting up the experiment the space around the plant stem in hole (i.) must be loosely and carefully packed with sterilised cotton or glass wool; hole (ii.) must be closed in a similar way.

After the young plants have grown in this liquid for about a week their roots should be removed into distilled water for a day or two, and then into a fresh supply of the culture fluid.

The vessels should be covered with black paper, for this precaution will minimise the growth of moulds and other small vegetable organisms in the fluid. Moulds are a great pest in connection with these culture experiments, hence all the precautions we have detailed above.

An isolated water culture experiment is of very little use. To be of educational value such experiments must be conducted in series. By this means we can find to what an extent plant growth depends on the individual chemical constituents of its supplied food. The following gives a useful series of experiments:—

1. Full culture solution.
2. Omitting potassium : by using sodium nitrate instead of potassium nitrate.
3. ,, sodium ,, potassium chloride instead of sodium chloride.
4. ,, calcium ,, magnesium sulphate and phosphate instead of calcium phosphate and sulphate.
5. ,, nitrates ,, potassium sulphate instead of potassium nitrate.
6. ,, chlorides ,, sodium sulphate instead of sodium chloride.
7. ,, sulphates ,, calcium and magnesium phosphates instead of calcium and magnesium sulphates.

8. Omitting phosphates: by using calcium nitrate instead of calcium phosphate.
9. „ iron salts.

The following are a few of the results which may be expected:—

(i.) Vigorous growth in 1, 3 and 6.
(ii.) A lack of green colour may occur in 9.
(iii.) Relatively little growth of others. It should be particularly noticed that 5 shows that plants derive their nitrogenous supply from the soil, and not directly from the air.

In practice it further becomes important to know the specific results of certain plant foods upon the growth and development of the plant. The cultivator has very different objects in view in the production of a good cabbage or a marketable tomato. In one case he must produce fleshy, succulent and tender leaves, while, in the other, his object is to produce an abundance of early though matured fruit. From experiment the gardener knows of three excellent plant foods, viz. nitrates, phosphates and potash salts, to which he has given the somewhat fanciful name of the "Golden Tripod." It is the minimum amount of these three present in the soil which, to such a great extent, determines the soil's fertility. If any one of them be wanting, no excess of the other two will make good the deficiency of the other. In other words, if one leg of the tripod fails, the plants will fail also.

Let us summarise briefly this characteristic action of these three important plant foods, again referring to their origin and retention in the soil.

1. *Nitrates.*
   (i.) Promote the vigorous growth of the plant as a whole.
   (ii.) Darken the green leaves.
   (iii.) Cause fruit-bearing trees to produce rank, coarse shoots and many leaves, rather than much fruit.
   (iv.) Nitrates in the soil are largely the result of bacterial action; even the nitrogen in manure must first be transformed in nitrates before it can enter the plants. Ammonia and nitric acid may be regarded as representing intermediate products.

2. *Phosphates.*
   (i.) Promote the production of fruit rather than foliage.
   (ii.) Promote early maturity.

(iii.) Are therefore of more use in the garden and orchard than they are in the field.

(iv.) No plant food appears so slow in its action, so difficult of access, as the natural phosphates of the soil. It seems there must be actual contact of the phosphorus-bearing compounds with the root hairs themselves.

3. *Potash.*

(i.) Increases the quality of the fruit.

(ii.) Increases the amount of sugar. Recent experiment has shown that photosynthesis cannot go on in the absence of potash.

(iii.) Fertile soils have remarkable power of fixing and retaining the potash. Some trace this to the presence of lime. The potash is made available by

(*a*) Carbonic acid from decaying humus or manure.

(*b*) Vegetable acids produced in the soil.

(*c*) The addition of lime or chalk.

4. **Rotation of Crops.**—It is a well-known fact that if the same crop is grown year after year the land becomes "sick of the crop." What causes this sickness, and how may it be remedied?

It is caused by the exhaustion of one or more of the particular foods which the plant requires, and it may be remedied by (i.) judicious manuring, (ii.) growing crops in rotation. For the first of these two methods the student is referred to one of the many manuals on Scientific or Practical Agriculture. We are only called upon here briefly to discuss the second.

Farm crops are usually divided into four classes :—

1. Cereals, *e.g.* wheat.
2. Leguminous plants, *e.g.* peas and beans.
3. Root crops, *e.g.* turnips.
4. Forage crops, *e.g.* clover.

These are sometimes described and reclassified, according to their effect on the soil, as

1. Exhaustive crops, *e.g.* cereals.
2. Restorative crops, *e.g.* leguminous, root and forage crops.

It must be remembered, however, that very often the so-called restorative crops would be exhausting if the whole of the produce were removed from the soil, which we shall see is not the case.

These facts, considered in conjunction with what we have said regarding plant food in the earlier chapters, point strongly to the advisability of alternating these two classes of crops, and in arranging a rotation we must bear in mind the following general rule:—

"Plants selected to follow each other should differ as much as possible in their modes of growth and general habits of life, and with regard also to the kinds of food they require in large proportion from the soil."

It is interesting to note the following in this connection:—

(i.) Different kinds of crops differ in their capacity for obtaining the various elements of plant foods. For example, clover obtains its nitrogenous food with greater ease than any corn crop. Clover, in common with other leguminous plants, like peas and beans, possesses small swellings or tubercles on its roots. (See Fig. 2.) These swellings are inhabited by colonies of bacteria, having the power of fixing within themselves the nitrogen obtained from the "ground air." The host plant avails itself of this nitrogenous supply on the death of the tiny organisms; and thus, since clover roots are "ploughed in" afterwards, the land is actually enriched in nitrates.

(ii.) Some crops have long roots, and others only shallow roots, so that it is an advantage to grow these two classes alternately, since they draw upon different depths of soil for their nourishment.

(iii.) Different kinds of crops are attacked by different kinds of insects, the ravages of which can be effectively checked by withdrawing for a year or more the plants upon which they feed.

(iv.) The land is always worked with greater convenience when a rotation is adopted, as some crops give better opportunities for cleansing the soil than others.

The following are among the most common rotations now in practice in different parts of the country:—

1. THE NORFOLK ROTATION.

1st year	... ...	Turnips
2nd ,,	... ...	Barley
3rd ,,	... ...	Clover (or grass seeds)
4th ,,	... ...	Wheat

The following rotation is in practice over large areas in the North of England. It is a five-course system:—

1st year	... ...	Oats
2nd ,,	... ...	Wheat
3rd ,,	... ...	Roots
4th ,,	... ...	Barley
5th ,,	... ...	Seeds

A variation of this is adopted in Devonshire, viz.:—

1st year	Mangels
2nd "	Wheat
3rd "	Turnips
4th "	Barley
5th "	Seeds

Which is sometimes modified into a six years' system, thus:—

1st year	*Mangels*
2nd "	*Wheat*
3rd "	*Barley*
4th "	*Turnips*
5th "	*Oats*
6th "	*Seeds*

The following gives a successful rotation adopted largely in the Lowlands of Scotland:—

1st year	Green crops
2nd "	Wheat or barley
3rd "	Clover
4th "	Oats
5th "	Potatoes or beans
6th "	Wheat

We will consider the Norfolk rotation in a little more detail. It will be seen that it realises almost all the general advantages of rotation given above. The two exhausting crops, barley and wheat, are separated by the two restorative crops, turnips and clover.

In the first year roots are grown; these require a light soil and a large quantity of potash, and little or no silica.

Roots are followed by barley, with its long fibrous roots, which require much silica and little potash compared with turnips. Leguminous clover follows the cereal barley, and has a shallow fibrous root, which requires lime in the soil, differing thus from the plants that precede it. Clover is especially suited to be followed by wheat, because the short roots of the former tend to bind the soil together, and to give a desirable firmness to the land. Then, too, sheep or other farm stock are turned on to the land to feed on the clover; this also tends to consolidate a light soil, besides supplying a certain amount of natural manure from the animals.

The wheat plant requires a heavier soil than clover. Its roots reach down to the lower layers of the soil, and thus draw upon a different region from that of the clover roots. Further, clover requires little or no silica, which is so necessary for the proper growth of wheat.

In closing this chapter on the "plant food supplied by the soil," the student is reminded that plants appropriate this food by means of

(i.) Water and carbonic acid.

(ii.) Bacterial and chemical actions.

These have been described in other parts of this book. The student is strongly advised to gather the facts together under the above heads, and to give special attention to the source and appropriation of nitrogen as a plant food. (See Summary.) Experience has shown that there is little danger in the exhaustion of the supply of the phosphates and potash of the "golden tripod" previously mentioned, but that there is a serious tendency to deplete the soil of its nitrates—hence the value of the process of inoculation previously referred to.

SUMMARY.

PLANT FOOD SUPPLIED BY THE SOIL.

The Constituents of Plants.

ORGANIC: 95 per cent.—Protoplasm, Woody Fibre and Cellulose, Starch, Sugar, Gum, Resin, Vegetable Albumin, Glutin, Globulin, Legumins, Oils and Fats.

INORGANIC: 5 per cent.—Silica, Lime, Potash, Soda, Ammonia, Magnesia, in combination with Hydrochloric, Phosphoric, Carbonic and Sulphuric Acids; Oxide of Iron.

Plant Ash Fallacy.—The real needs of a plant under ordinary conditions are greatly at variance with those deduced from the chemical analysis of the plant ash.

By **Water Cultures** we can accurately discover the mineral raw food materials essential for plant life.

A culture fluid consists of:—

Nitrate of Potassium, *Chloride* of Sodium, *Sulphates* of Calcium and Magnesium, and *Phosphate* of Calcium.

The farmer, by experimental plots, has further investigated the action of Nitrates, Phosphates and Potash on plant life.

Rotation of Crops and Exhaustion of the Land.

Reasons for Rotation:

1. Different capacity of obtaining food.
2. Varying length of roots in different plants.
3. The avoidance of insect ravages.
4. Greater convenience of working land.

NORFOLK ROTATION—a four years' course:—

Crops.	*Nature.*	*Chief Food.*	*Roots.*	*Soils.*
Turnips	Restorative	Potash	Bulbous	Light
Barley	Exhausting	Silica	Long Fibrous	Heavier
Clover	Restorative	Lime	Short Fibrous	Light
Wheat	Exhausting	Silica	Long Fibrous	Heaviest

The Plant obtains its—

(1) CARBON from the air, by the interaction of the Carbonic Acid Gas and water.

N.B.—In the soil carbonic acid acts

(i.) Chemically—liberating other foods.

(ii.) Mechanically—as a solvent.

(2) OXYGEN AND HYDROGEN are obtained from the soil in the form of water.

N.B.—Oxygen is also obtained from the Nitrates, Phosphates and Sulphates.

(3) NITROGEN is obtained—

(*a*) Not directly from the air, although by the action of lightning in its passage through the air, the Nitrogen combines with the Oxygen. The compound formed is dissolved by the rain and supplies Nitrogen to the plant.

Ammonia, present in small quantities in the air, also supplies Nitrogen by the agency of the rain as above.

(*b*) From the soil by—

(i.) Chemical Action, resulting in the formation of Nitrates by the action of Ammonia and Nitric Acid.

(ii.) Bacterial action or fermentation, which no doubt yields Nitrogen to the plant.

(4) SULPHUR from Sulphates.

(5) PHOSPHORUS from Phosphates.

◆

PART III.

PRACTICAL GARDENING.

CHAPTER XXVII.

Work done in the Garden (I.).

Practical Cultivation.—In this chapter we propose to describe the practical cultivation of some of our common garden vegetables. Since these form such stable and important foods for man, a brief study of their growth and propagation is as interesting as it is desirable in a book of this kind.

It must ever be remembered, however, in this connection, that "an ounce of practice is worth a pound of theory," and the only sure road to discovery, progress and success is by carefully contemplated experiment.

1. **Lettuces.**—These constitute perhaps the most valuable "salad" that is grown in our gardens, and there is a constant demand for them. With skilful cultivation and proper appliances a supply can be had practically all the year round. The numerous varieties are divided into two distinct types, viz. (i.) the Cabbage, and (ii.) the Cos. The former are dwarf plants, the leaves of which turn in naturally and form hearts much in the same way as in cabbages, hence the name, Cabbage lettuce. The Cos varieties are of upright habit and generally require tying up when nearly fully grown, to induce them to produce crisp white hearts. It is important to remember that this tying must be done when the plants are dry.

PROPAGATION OF LETTUCE.—*This is by seed. Any fertile soil* will produce good specimens, but it is necessary to have a good subsoil, as proper drainage is essential.

For crops during the summer, the first sowings are made in January and February, in gentle heat under glass, the seedlings hardened off and planted in a warm position out of doors in April. In every stage of growth they must be well watered, and the earth around them constantly disturbed to extirpate slugs and snails. Successional sowings may be made at intervals of three or four weeks until the end of June. The seeds should be sown by shallow drills, twelve or fourteen inches apart, and the plants thinned when large enough to handle, until they are nine inches asunder in the rows. The thinnings are, of course, useful for chopped salads, and should therefore not be thrown away.

For plants to stand the winter and to be ready for cutting in the spring, two sowings should be made: one in the third week of August and the other the second week in September. Transplant these seedlings when about two inches high to a well-drained sheltered site out of doors. A few may be put in a cold frame, using plenty of sand on the surface of the soil. Free ventilation during clear weather must be given to those grown in frames, and they must be carefully watered and shaded until well established. It is well to protect them with matting in cold weather during the night, and in the day-time the temperature should be kept between 65° and 80° F.

Slugs and snails are especially destructive to autumn-planted lettuces, but they may be almost exterminated by the proper application of powdered lime, which should be shaken round about the beds and frames to bar their approach. (See Appendix—" Animal Pests.")

KINDS OF LETTUCES.—Good varieties for sowing in spring for summer use are:—

(i.) *Cos Lettuces*:—Paris White and Hooper's Incomparable.

(ii.) *Cabbage Lettuces*:—Mammoth White, Superb Green, All the Year Round, Drumhead.

Varieties for standing the winter, *i.e.* for sowing in Autumn:—

(i.) *Cos Lettuces*:—Black-seeded Bath, Moorpark.

(ii.) *Cabbage Lettuces*:—Hammersmith Hardy Green, Golden Ball, All the Year Round.

Any good seedsman's catalogue will give the student gardener most useful information concerning the many new and old varieties, as well as a series of excellent illustrations.

2. **Cabbages** form one of the most useful vegetables that we have, and numerous varieties are propagated. Before planting any cabbages the ground should be trenched two spades deep and a liberal quantity of well-decomposed farmyard manure added to the soil.

PROPAGATION OF CABBAGES.—Propagation is by seeds. Any well-worked, moderately rich soil suits them, provided it has an adequate supply of lime in its composition. Lime is the best preventative of "Clubbing," a fungoid disease that causes large swellings on the underground portion of the stems. It is very unwise to grow cabbages or any green or cruciferous crop on the same site two years running on account of this fungus. (See Appendix.)

Seeds are sown in the open in July and August for specimens which will be ready for cutting in the spring; in March for summer use; and in June for late autumn cuttings. Sow the seeds thinly and broadcast on a prepared bed of fine soil, and transplant the seedlings to their permanent quarters, trenched and manured as above described, when about three inches high. The distance apart to plant them varies with the sort grown. For the small varieties, rows about eighteen inches apart and fifteen inches between each plant will suffice; but for larger sorts the rows should be two foot apart and the plants eighteen inches asunder. It is highly important that the young plants be thinned early in the seed bed, so as to prevent them becoming drawn or "leggy." Cultural details will consist in frequently hoeing the soil between the plants. Those planted in the autumn should have some soil drawn up to their stems during November, for otherwise these have a most tantalising tendency to go to seed instead of "hearting-up" in the spring. Unfortunately, there is no entirely satisfactory remedy for this trouble. Some varieties are, however, less prone to it than others, "Ellam's Early" being one of the least liable to behave thus. When the plants are well established a pinch of nitrate of soda sprinkled round each is a splendid stimulant. Insect enemies are numerous, the worst being the cabbage or white butterfly, which lays its eggs on the plants in May and June and onward through the summer. The caterpillars soon hatch out and devour the leaves and thus ruin the crop. Careful watching and hand-picking afford the only reliable remedy.

KINDS OF CABBAGES.—Good varieties are—

(i.) For autumn sowing:
Ellam's Early and Flower of Spring;

(ii.) For spring sowing:
Defiance and Enfield Market;

(iii.) For summer sowing:
Winningstadt and Rosette Colewort.

The above varieties are often classified in two divisions:—(*a*) open headed and (*b*) close or drumhead varieties.

3. **Cauliflowers** are another most valuable green crop, the delicate flavour of well-grown specimens rendering them very popular. The cauliflower differs from broccoli in being an annual, and is therefore of more rapid growth.

PROPAGATION is by seeds. The soil must be well worked, of a medium texture, and rich in humus. It is necessary to check the outer growth at times in order to secure good heads. An early sowing may be made in shallow boxes of light soil, under glass, in January or February, the seedlings being "pricked" off into other boxes and gradually hardened off for planting out in a well-sheltered position at the end of April. Other sowings may be made in the open during April and May, the plants thus obtained forming the general crop for cutting during September, October and November. The distances apart to plant are the same as those advised for cabbage; and the remarks about hoeing, giving nitrate of soda, and injurious pests apply equally to cauliflowers as to cabbages.

It is interesting and useful to note that if a sharp frost threatens in the late autumn those plants with partly developed heads may be lifted from the soil entire and hung heads downwards in a cool dark outhouse, where they will remain good for quite a fortnight. Another method for keeping cauliflowers fresh and crisp is sometimes advised. They are cut with six or eight inches of the stem attached, and the leaves are clipped off square with the surface of the flower. The stem is then stuck into a layer of moist sand six inches deep, which has been spread over the floor of a dark dry cool cellar. In this way they keep good for weeks, and for a much longer period than when kept as first described. However, it is evident that somewhat more trouble is attached to the latter method.

The ill-effects of slight frosts and heavy rains may be prevented by breaking the mid-ribs of two or three of the largest leaves and then bending the tops over the head.

KINDS OF CAULIFLOWERS.—The best varieties are:

Early season:—Sutton's Favourite.
Mid season:—Walcheren.
Late season:—Veitch's Autumn Giant.

4. **Beans** constitute one of our most important leguminous crops. We have already considered the bean plant from a scientific standpoint; we now turn to its practical cultivation.

Garden beans are divided into three distinct types, viz.:—

(i.) The broad bean.
(ii.) French or kidney bean.
(iii.) Scarlet runner.

(i.) In **Broad Beans** there are again two types, the Broad Windsor and the Long Pod varieties. The former has a broad and rather short pod, and is undoubtedly the best flavoured. The latter, as its name implies, has long pods, with rather small seeds.

PROPAGATION is by seeds. The best soil is one of a clayey nature, but it must be trenched and incorporated with well decomposed farmyard manure. A dressing of superphosphate of lime at the rate of four ounces to the square yard at sowing time is most beneficial; it should be carefully raked into the surface. An early sowing may be made in November if a well-drained, sheltered site is available. Other sowings are made in February and March. The rows should be two or three feet from each other, and each seed dropped about one foot from its neighbour and about two inches below the surface.

Mice and birds often steal the seeds. To prevent this, place them in paraffin for three minutes and then dust them with red lead. The black dolphin or aphis is a great pest of this crop, infesting the tops of the shoots. Pinch out the tops and burn them as soon as the pest is observed and then spray the plant with a solution of soft soap and quassia. Or there are other specific remedies in the form of insecticides—these are also effective.

KINDS OF BROAD BEANS:—

(*a*) For autumn sowing:
  Mazagan and Dwarf Fan.

(*b*) For spring sowing:
  Green Windsor and Seville Long Pod.

(ii.) **French** or **Kidney Beans** are mostly dwarf, but a few varieties have a climbing habit.

PROPAGATION is by seeds. The ground for these should be prepared as advised for broad beans, but the soil may well be of a more open and organic nature. A light rich loamy soil is regarded as ideal for the growth of French beans.

For forcing purposes seeds are sown in boxes and pots under glass as early as January, but for general use the first sowing is made under glass early in April, and the plants are set out about the second week in May. The first sowing outdoors is made at the end of April, and successional sowings are continued until the middle of July. The plants, unlike those of the broad bean, are easily injured by frost. It is an advantage to give early and late crops the shelter of a wall or fence.

The rows should be two feet apart, and the plants thinned until they are eighteen inches from one another in the rows. In all cases the seeds should be sown about one inch deep. It need hardly be said that vacant spaces where seeds have missed should be filled by transplanting from where they are too thick, and this must be done carefully with a trowel.

The forcing of French beans has become so common of late years that it will repay us to describe the process a little more in detail. It is commenced generally in September, at first in cold frames and afterwards in hot beds, and the like. The hot bed is covered with nine or ten inches of good earth. The temperature is taken from time to time, and when it has become regular the seeds are drilled a foot apart in rows, which are half that distance from one another. When the weather allows it air must be freely admitted, and the temperature should be maintained between 60° and 75° F. It is beneficial to take the chill off the water used in watering them. The plants should be occasionally syringed, especially on the under sides of the leaves, to avoid a fairly common pest (thrip) which attacks them. A small stake or other slight support should be placed against each plant.

KINDS OF FRENCH BEANS:—

(a) Dwarf.
Canadian Wonder;

(b) Climbing:
Tender and True.

(iii.) **Scarlet Runner.**—This plant is quite similar in character to the dwarf French beans, so that the foregoing remarks (with the exception of forcing and distances to sow) apply equally well to this kind of bean. For scarlet runners the rows, when stakes or poles are used for the plant to climb over, must lie five feet apart, but the seedlings need only be about six inches apart in the rows. Sowing in shallow trenches is now much in vogue, as it greatly facilitates watering. The young plants of these beans should be dusted with ashes or slaked lime to prevent them being devoured by slugs. It is interesting to notice here the practice of many London market gardeners, in cases where the gardens lie exposed. They plant Brussels sprouts in early summer between the rows of runners and by the end of the summer these sprouts grow tall and afford shelter from the harmful early frosts. In this case, however, the gardeners generally keep the plants bushy by nipping off the "*runners*" as soon as they appear.

KINDS OF SCARLET RUNNERS.—The Scarlet Emperor and Elephant are among the best.

5. **Peas** may be regarded as the queen of vegetables. They are propagated by seeds, which may be sown every three weeks from January to June, giving us a perfect succession.

Any well-cultivated soil that is rich in phosphates will produce a good crop of peas. There must be no doubt about the thoroughness of the cultivation, for, in this case, so much depends upon it. The soil must be dug two spits or spades deep at least, and plenty of well-decayed natural manure should be mixed with the bottom spit or lower earth. Manuring should not take place after the seeds have been sown.

The varieties differ so much that only general remarks as to their treatment can be made here. The first sowing for an early crop is in boxes or pots of fertile soil or even on strips of turf, under glass, at the end of January or early in February. The plants are hardened (that is, are gradually inured to cold) ready for planting out in April. Strong heat must be strictly avoided. The first outdoor sowing is made in a sheltered position in February, or early March, in late localities. It is best to choose a hardy dwarf variety, such as William I., for these early out-door sowings. From thence onwards until the end of July sowings may be made at intervals of three weeks. As in the case of beans, the seeds should be dressed before sowing with paraffin and red lead. The later the sowing the shallower the trench should be. The distance apart of the rows will vary with the height of the variety, a good general rule being to make the distance about the height of the plant, which of course depends upon the kind of pea grown. The seedlings must be thinned so as to stand two inches asunder. Copious watering is necessary during dry weather when the pods are "setting." It should not, however, be thrown over the leaves, but poured on the ground along the rows. When the plants are three inches high they should be earthed up, and the ground occasionally hoed. Sticks for support may be used when the tendrils appear: the shorter varieties do not always require this support. Mildew is the chief disease which is liable to attack the peas, especially during hot, dry weather. Copious and careful watering, with the application of liquid manure, will generally prevent it.

KINDS OF PEAS :—

(i.) For early crop: William I., Chelsea Gem, Sutton's Centenary Marrowfat.

(ii.) Mid season: Peerless Marrowfat and Eureka.

(iii.) Late season: Gladstone.

6. **Beetroot** is a great favourite with most gardeners. There is a good demand for it, as it forms a valuable salad. According to chemical analysis, it contains bulk for bulk much more nutritive matter than any other root, except perhaps the potato. It is well known that beetroot supplies great quantities of sugar, and the red varieties are particularly nutritious owing to the nitrogenous matter they contain.

There are three chief types, viz. :—

(i.) Round or turnip rooted;

(ii.) Long rooted;

(iii.) Spinach beet.

The leaves of the spinach beet are boiled and eaten as spinach, while the roots of the other varieties form a stable and everyday food. There is also the Chilian beet, the leaf stalks of which possess bright colouring of many lines, so that they are valuable ornamental plants for the flower garden.

PROPAGATION is by seeds. A well-worked soil that has been thoroughly manured for a previous crop, such as onions, is the most suitable; very rich ground not being advisable except for the Spinach and Chilian types.

Sowings are made about the first or second week in May, in drills 1½ inches deep and 1 foot apart, the seedlings being thinned to 1 foot asunder in the rows, as soon as they are large enough. Frequent hoeing during summer is essential. The round or turnip-rooted sorts are the best for early use, the long varieties being "lifted" in autumn, the tops twisted off, and the roots stored in a cool place in sand, ashes or dry soil for use in the winter. In lifting and storing great care must be taken not to injure the roots. If any are broken, bleeding will ensue, and loss of colour when cooked will be the result. To gather spinach beets, the largest outer leaves should be removed first, and the inner crown left to grow to give a future supply.

Slugs and sparrows are very fond of young seedlings. Dusting with ashes when damp will circumvent the attacks of the former, while the latter may be kept at bay with old fish netting or strands of black cotton fastened to sticks a few inches from the ground.

What gives the pronounced red colour to the common beetroot?

KINDS OF BEETROOT :—Good varieties are :—

(i.) Round, Sutton's Globe.
(ii.) Long, blood red, Pragnell's Exhibition.

7. **Carrots** are hardy biennials, and form an important and profitable crop for the garden. Carrots are propagated by seeds. The soil should be of a rather open or sandy nature—light but deep—especially for early crops, but good roots of the late variety are frequently obtained in good condition from heavier soils. A sandy loam or peat is highly suitable. Deep digging or trenching is essential, but heavy manuring is not advised. It is much better to manure heavily the previous year and secure a crop of some other vegetable, such as celery, before we sow the carrots, which may be done without further manuring.

Carrots may be roughly divided into two classes or types, viz. :—

(i.) The Shorthorn (or stump-rooted);
(ii.) The long-rooted carrot.

The former is usually grown for early crops, and the latter for main crops and for use during the winter.

There is the greatest demand for the stump-rooted varieties, as they develop the better flavour. The first sowing may be made about the third week in February, choosing a warm and sheltered site. The rows should be shallow and about 8 inches apart, and the seeds should be covered with ½ inch of sandy soil, and the surface made firm. Thin out the seedlings for this crop until they are 2 inches apart.

The main sowings are made during March and April, allowing a distance of 10 to 12 inches between each row, and thinning the seedlings until they are 6 inches apart in the rows. Sowings of early Shorthorn varieties are often made as late as August, September and October, the roots being pulled and used when large enough. Carrots are also forced in frames on gentle hotbeds during the winter. It can easily be arranged for a light to be placed above the frame if there is any need of hastening the crop, which is often desirable to meet the demand.

KINDS OF CARROTS:—

For early sowing: Early Gem and Early Nantes.

Mid season: James' New Intermediate.

Late season: Long Red Surrey, Altringham.

8. **Turnips** are another staple vegetable of the farm and garden. They are easy to grow, but owing to the ravages made among them in their young state by the turnip flea beetle a crop is often disappointing. The soil most suitable for the turnip is a light rich loam, but any well-tilled soil, provided it contains a good amount of lime and potash, will suit. Successional sowings are made from the end of February until the middle of May for roots which are to be used during the summer; and at intervals from the middle of July until well into September for winter crops.

Sow in shallow drills 1 foot apart, and thin the plants early to half that distance from plant to plant. During dry weather it is frequently necessary to water the drills before sowing the seeds, to ensure germination.

To prevent the attack of the black turnip fly (or flea) referred to above, the young seedlings must be frequently dusted during dry weather with gritty dust or ashes, this operation being performed whilst the leaves are damp with dew, so that the dust adheres to them. Clubbing, due to a fungus, sometimes affects turnips. (See Appendix.) We have already dealt with its treatment in the case of cabbages.

Kinds of Turnips:—Good varieties are:—

(i.) For summer:—Early Red Milan,
Early Snowball.
(ii.) For winter:—Chirt Castle,
Black Stone.

9. **Celery.**—This vegetable is perhaps one of the most valuable occupants of our gardens. Propagation is by seeds. Well cultivated, heavily manured soil is absolutely essential if good heads are required. For its proper growth it requires plenty of water, so that if a rather damp site is available so much the better. All checks to growth must be strictly avoided. Early in March is the time to sow for the first crop, using shallow boxes of rather light soil and placing them on a gentle hot bed. When large enough "prick" the seedlings out into a well-prepared bed of soil on a still milder or gentler hot bed, incorporating some flaky leaf soil with the compost. The plants from this sowing, after the customary gradual hardening, should be quite ready to go into trenches by the middle of May. A main sowing may be made on a prepared bed of rich loamy soil, in the open, at the end of March, and the seedlings are transferred as soon as they can be handled to other beds of good soil.

The trenches for the well-developed, robust plants should be prepared two or three months before they are required. They must be twelve inches wide by ten inches deep, and well-rotted manure must be mixed with the bottom layer of soil. The trenches should be at least five feet apart. The plants from the main sowing should go into the trenches at intervals from the first week in June till the third week in July.

Two rows may be grown in one extra wide trench, but a single row is most convenient. Shading and watering will be necessary for a few days if the weather is sunny, and good soakings with water must be afforded during periods of drought.

When the plants have well developed their centres earthing is necessary. To perform this operation, all suckers or side shoots are removed, and the leaves of each plant are gathered up closely together and then some fine soil is placed and made fairly firm around the plant. It is preferable to make only two or three earthings, and it can be done in one operation. When the earthing is often repeated there is a tendency for the celery to "pipe" or become hollow. The usual practice in the Midlands, when exhibition specimens are required, is to tie brown paper round the plants either in lieu of, or supplementary to, earthing. The plants should grow until they are fourteen or sixteen inches in height before being earthed up, and the operation is most satisfactorily carried out by two persons working together.

The larvæ of the celery fly are the worst pest. The fly pierces the leaves and lays its eggs in the succulent tissues. The maggots hatch out and tunnel between the tissues of the leaves, causing whitish blister-like patches. Pinching the maggots between the fingers and thumb as soon as they are seen is the only effective remedy.

KINDS OF CELERY:—Good varieties are:—

(i.) Early: Sandringham White and White Gem.
(ii.) Main Crop: Sulham Prize and Leicester Red.

10. **Onions.**—Varieties of this well-known pungent bulbous salad vegetable have been grown in Europe from time immemorial. Their contained grape sugar gives them great dietetic value, whilst, in addition, they possess medicinal properties of no mean order. They are divided into two distinct types, viz. those sown in spring and those sown in autumn. The former are most generally grown, and are the most useful. Propagation is by seeds. The spring sowing is now made largely under glass, shallow boxes being used for the purpose. The end of January or early February is the time most favoured. The seeds should be sown thinly and the plants kept fairly warm by being placed near the glass. When about two inches high prick them off two inches apart each way into other boxes of pliable soil containing some coarsely sifted rotted manure and flaky leaves. Give cool treatment, but keep them near the glass and finally transfer the plants to a bed in the open, about the second week in April. Coddling in any form must be strictly avoided.

Sowing in the open, where glass is not available, is generally done about the second week in March. In this case, sow in shallow drills one foot apart and thin the seedlings early to nine inches asunder in the rows, and make the surface of the land firm after sowing. Deep trenching of the bed is highly essential in the autumn if good bulbs are desired. At the same time plenty of well-decomposed manure should be incorporated with the soil. The gardener must keep down the weeds by frequent hoeing, which operation will make the surface fine and thus prevent the evaporation of moisture. The bulbs must be fully grown and ripened before they are lifted for storing. The main crop will be quite ripe about the beginning of September and the plants will assume a withered appearance. They should then be taken up and laid out in a sunny place to dry. They should be left to the air and the sun for a week or two, being covered over at night, and then stored free from dirt in a cool but frost-proof structure. The autumn sowing is made at the end of

August, the seedlings being thinned or transplanted as desired. These form quite large bulbs for use in early summer.

The worst pest of spring-grown onions is the onion fly. This pierces the leaves, lays its eggs in the tissues, and the maggots, quickly hatching out, eat their way into the young bulbs. It is to circumvent this pest that sowing under glass is advised, as the plants are then too old and tough for the fly to pierce in May, the time when it usually appears. Onion mould is a fungoid disease that is frequently very destructive. Dusting with slaked lime while the plants are damp, as soon as the disease causes the tips of the leaves to turn yellow, sometimes prevents disaster. If, unfortunately, the disease gets too great a hold for this treatment, burn all the badly infested plants and do not grow onions on the same site for two or three years.

KINDS OF ONIONS:—Good varieties are:—

(i.) For spring sowing: Ailsa Craig, Rousham Park Hero and Bedfordshire Champion.

(ii.) For autumn sowing: Lemon Rocca and Red Tripoli.

11. **Potatoes** are the most important vegetable grown in the United Kingdom, and many excellent varieties are cultivated. These different kinds have been obtained by careful selective hybridisation, a process the value of which cannot be over-rated, since it enables the scientific gardener to produce new varieties of any vegetable, fruit or flower. Hybridisation or cross breeding in the case of the potato is in itself a very simple process.

It may be carried out as follows:—

(i.) When the parent plant shows its flower buds, they are all removed except the one or two which are to be pollinated.

(ii.) When these one or two flowers open, the stamens should at once be cut away with a pair of sharp scissors, taking special care not to injure the pistil.

(iii.) The whole plant should then be covered with gauze to prevent premature fertilisation by insect agency.

(iv.) In fine weather, two days after the flowers have opened, the pistils which remain are brought into contact with the pollen of another variety. This operation may be performed two or three times in order to ensure a successful result.

(v.) As soon as fertilisation has taken place, generally within a few hours after the pollen has been applied, the gauze may be removed.

The seeds resulting from this process unite, to a greater or less extent, the characteristics of the two plants taken.

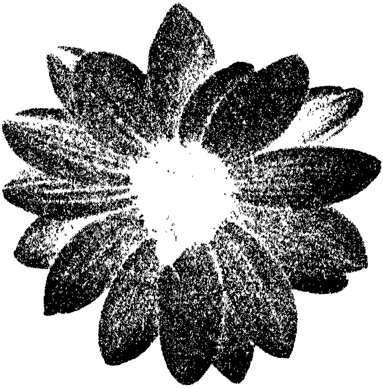


Plate XIX.—A NATURAL AGENT OF CROSS POLLINATION.

Ordinary Propagation of the Potato is made by seeds and by sets or tubers. Except for producing new varieties the latter mode is generally employed. The eye of a potato, it has been seen, consists of several buds, usually from two to six, but when planted in the usual way only one, or at most two buds start to grow, the rest remain inactive. Yet when the eye is subdivided into as many sets as there are buds, every germ shows active growth. Taking, as an average, three buds to each eye, one pound of tubers would give about 100 shoots. The sets being small should be planted carefully in pots, containing a light soil of rich loamy character, early in February. These should be placed in a frame where the temperature is maintained at about 52°. Little or no water should be given until the sets have commenced to grow.

When the plants reach a height of six inches their tops should be taken off and planted in single pots. If the temperature be raised to 65° or 70° F. these cuttings will strike freely. The ideal soil for the growth of potatoes is a deep, well-drained light open soil of a sandy loamy character. The land must be well tilled and manured.

The earliest crops are obtained by a system of forcing under glass, but the general planting is done in the open. In practice, it is found that tubers weighing about two ounces each are an ideal size for sets, and are infinitely better than cut tubers. These small tubers should be selected at the time of lifting in the autumn, and stored in a cool frost-proof place until required (in early February). It is also desirable that too many sets should *not* be obtained from one bud, so that the following method is more commonly adopted. The small tubers are laid out thinly, eyes or buds upwards, on a tray or shallow box and exposed to the light in a cool place. By this system stout green shoots are produced, two of the strongest only being retained to each set. The earliest sorts of potatoes may be planted in a sheltered spot in March, and fresh batches every two or three weeks until early in May. Plant five inches deep in drills, which may be, for these early sorts, in rows twenty inches apart and the plants one foot apart in each row. For later and stronger-growing kinds these distances should be increased.

When the shoots are nine inches to a foot in height, earth must be drawn up to them in the form of a hollow-topped ridge, this prevents tubers becoming green, and also prevents the spores of the potato disease being transmitted to the tubers. Figs. 245, 246 have previously shown us how "earthing" increases the number of subterranean runners and, consequently, the number of tubers produced.

The potato disease is a terrible fungoid pest that attacks the foliage, and eventually, the tubers. Spraying with Bordeaux mixture early in July and at fortnightly intervals until the end of August will tend to prevent attacks. The tubers for culinary purposes may be stored for the winter in a dark frost-proof structure or in pits in the open.

KINDS OF POTATOES:—The question of sorts to grow can never be perfectly determined without experiment. The following, however, may prove a useful guide:—

(i.) For light soils:—Try almost any kind, avoiding Magnum Bonum, Covent Garden, Perfection, Alpha and Schoolmaster.

(ii.) For heavy soils:—Try the varieties given in (i.), and also Grampian, Ash Leaf and Regent.

(iii.) Early varieties are:—Sutton's A1 and Sharpe's Victor.

(iv.) Second Early varieties are:—Sir John Llewellyn and Sutton's Supreme.

(v.) Main Crops:—Factor, Up-to-Date and King Edward VII.

◆

SUMMARY TO CHAPTER XXVII.

VEGETABLES (FROM SEED).	KINDS.	SOIL REQUIRED.	TIME OF SOWING.	DISTANCE BETWEEN ROWS&PLANTS.	REMARKS.
Lettuce ..	i. Cabbage. ii. Cos.	Fertile soil with good drainage.	*For Summer*, January to June.	Rows 12 ins. Plants 9 ins.	Lime will prevent attacks from slugs.
Cabbage ..	i. Open headed. ii. Close or Drum-headed.	Good soil, trenched, manured and limed.	*For Spring use*, July to August. *For Summer*, March. *Late Autumn*, June.	Rows 2 ft. Plants 1½ ft.	Nitrate of Potash or Soda stimulates growth and gives greenness.
Cauliflower	Early, Mid and Late Season.	Medium soil with much humus.	*Early*, Jan. and Feb. *Mid*, April and May. *Late*, Oct. and Nov.	Rows 2 ft. Plants 1½ ft.	Early sowings under glass.
Beans	i. Broad Beans. (*a*) Broad Pods. (*b*) Long Pols. ii. French Beans. (*a*) Dwarf. (*b*) Climbing. iii. Scarlet Runners.	Good clayey soil, limed with superphosphate and manured.	Different for different kinds, see Text.	Rows 2 to 3 ft. Plants 1 „ 1½ „ For iii. Rows 5 ft. Plants 6 ins.	French Beans are often forced by frame and hot-bed. Dress seeds with paraffin and red lead.
Peas	Early, Mid and Late Season.	Good soil, rich in phosphates and well cultivated	Every 3 weeks from January to June. January, frame. February, outdoors.	Rows about height of plant. Plants 2 ft.	Copious and careful watering prevent mildew.
Beet	i. Turnip Rooted. ii. Long Rooted. iii. Spinach Beet.	Not too rich a soil: manured for previous crop.	1st or 2nd week in May.	Rows 1 ft. Plants 1 ft.	Frequent hoeing necessary; avoid bleeding.

SUMMARY TO CHAPTER XXVII.—*continued.*

VEGETABLES (FROM SEED).	KINDS.	SEED REQUIRED PER ACRE.	SOIL REQUIRED.	TIME OF SOWING.	DISTANCE BETWEEN ROWS & PLANTS.	REMARKS.
Carrots ..	i. Short. ii. Long Rooted.	8 ozs.	Sandy or sandy loam, light and deep, manured for previous crop.	*Early*, February. *Main*, March and April. *Late*, Aug. and Sept.	Rows 12 ins. Plants 6 ins.	Early carrots by frame and hot-bed.
Turnips ..	i. Summer. ii. Winter.	16 ozs. 6 ,,	Well tilled, light rich loam.	*For Summer Roots*, February to May. *For Winter*, July to September.	Rows 12 ins. Plants 6 ins.	Dust with ashes to prevent fly.
Celery ..	i. Early. ii. Main Crop.	2 ozs.	Heavy soil, well cultivated and manured, damp site.	Beginning of March for early crops. End of March for outdoor.	Rows 5 ft. Plants 6 ins.	Celery requires plenty of water. Transplanted to trenches 10 ins. deep.
Onions ..	i. Spring. ii. Autumn.	12 ozs.	Light friable soil with much humus.	*Spring*, Early Feb., boxes and glass. Outdoor, March. *Autumn*, End of August.	Rows 12 ins. Plants 9 ins.	Watch for, and remove onion fly and mould—dust with lime.
Potatoes .. From seed, sets & tubers	i. Early. ii. Main.	1½ bushels. 8 ,,	Light soil with rich loamy nature.	"Sets" in frames February, transplanted March till May.	Rows 20 ins. Plants 12 ins.	Draw up the earth around the stems.

CHAPTER XXVIII.

Work done in the Garden (II.).

In this chapter we shall deal with the propagation of plants by cuttings, layering, budding, grafting, and by corms and bulbs.

1. **Propagation by Cuttings, Layering, Budding, and Grafting.**—In the preceding chapter we dealt with a group of garden vegetables that are, with the exception of the potato, usually propagated by means of seeds. We have already seen that this is a highly developed natural and sexual method of reproduction, and it has its advantages and disadvantages. Gardeners frequently find it desirable and necessary to adopt some artificial and vegetative means of reproduction. Three of the chief methods employed are by:—

(i.) Cuttings;
(ii.) Layering;
(iii.) Budding.

We shall also briefly refer to Grafting.

(i.) CUTTINGS are made by taking portions of young wood from the old plant, preparing them in a certain manner, and then inserting them in a suitable soil or compost to enable them to make new roots, and thus lay the foundation of a new plant. Cuttings may be roughly divided into two groups, *viz.* soft wooded and hard wooded. The former consist of young shoots of soft, partly ripened wood, and the latter are made from young shoots of the current year, which have finished their growth and become hard (or ripened).

Two common plants that may be extensively reproduced by means of soft-wooded cuttings are geraniums and bedding calceolarias, and these may be taken as types of plants thus propagated. With an average amount of care and knowledge the beginner may obtain most satisfactory results. Non-flowering shoots of these plants are removed from the old ones (at the end of August for the geranium and a month later for the calceolaria), taking the cuttings so that seven or eight leaves remain on each. Then with a sharp clean knife cut squarely and precisely just below a node or joint. After this cut (not pull) off about four of the lowest leaves, so that rather more than a third of the stem is left bare. The cuttings are then ready for setting or "insertion." Thorough drainage is most essential for soil in which cuttings are to be rooted, and it is a good general rule to make it of a much more sandy nature than that in which the old plants are growing. A layer of sand a quarter of an inch deep, should, generally speaking, be placed on the surface of the soil before planting the cuttings. The cuttings of the plants, now under notice, are usually rooted in well-drained boxes about three inches deep, the soil being made comparatively firm.

With a blunt-pointed stick a hole should be made about a third as deep as the length of the cutting to be inserted. The stem of the cutting should rest on the bottom of the hole. This is a very important point, as, otherwise, if a hollow space is left beneath the cutting no roots will be emitted. After this, thrust the stick into the earth near the stem, and press the soil tightly up to the latter. It is a mistake to insert soft-wooded cuttings more than a third their length, and overcrowding must be strictly avoided by planting the cuttings so that each stands clear of its neighbour. It is necessary to water them once with a fine-rosed can, and then stand the boxes in a cold frame, keeping the lights closed for a week or more. When the weather is favourable, air should be admitted. Probably more soft-wooded cuttings are killed by over-watering than by any other means. It induces the formation of moulds which attack them all too readily. It must be remembered that a cutting has no roots with which to imbibe water, and the soil should never be wet for long. On the other hand, it must not be allowed to become dust dry; the thing to aim at being to keep the earth pleasantly moist. The season of taking the cuttings, and the methods of rooting, will, of course, vary with the nature of the plant being dealt with. Thus, chrysanthemum cuttings are taken from the end of December until the end of March, and are inserted singly in small pots of sandy soil.

Hard-wooded cuttings are usually taken in autumn, or about the second week in November. Currants, gooseberries, roses, and ornamental shrubs are largely propagated by this method. Firm and healthy shoots of medium thickness are secured by cutting the base squarely with a clean sharp knife immediately beneath a node or joint. The soft tip of the shoot is then cut away until a plump bud is reached, situated on firm, well-ripened wood. In the case of red and white currants, the cuttings must have all the buds, with the exception of four at the top removed. Black currants and rose cuttings should have no buds taken away.

When thus prepared, the cuttings are inserted in trenches, opened for the purpose on a well-drained, rather sandy soil, in the open. As before, they should be planted a third—some authorities say from a third to a half of their own depth. Fill in the trench with fine soil, and tread it firmly round them. These trenches should be about fifteen inches apart, and each cutting ought to stand about nine inches from its neighbour. If all goes well, they will root the following spring, and make a fair amount of growth during the summer.

In the following October, *i.e.* one year after the cuttings were inserted, the young plants may be removed to their permanent quarters.

(ii.) LAYERING is a modification of propagation by means of cuttings, the idea being to get the shoot rooted before it is totally severed from its parent. Branches of plants are pegged down to the soil until they send out roots, they are then detached from the parent. Carnations are almost entirely propagated by this method, and the following brief description of the operation may be taken to apply to other plants so reproduced.

The time for layering carnations is the end of July, or immediately the plants have finished flowering. If we examine our carnation then, we shall find a number of sturdy shoots, three or four inches long that have not produced flowers. These are the ones to layer, in order to produce new plants to flower the following summer. The advantage of this method over seed propagation is evident. (*See Chapter XVI., Sections* 1, 2.)

A small-bladed and very keen-edged knife, some wire pins, like large hairpins, and a good box of finely sifted friable soil will be required. Now take one of the flowerless shoots, and at a point about four inches from its apex remove the leaves so as to have about two inches of the stem bare at this point. On the under surface of the bare portion of the stem a cut is made carefully halfway through the tissue, then with a twist of the knife the stem is split upwards towards the top of the shoot for a distance of about one inch.

If this is properly done a tongue or loose portion of the stem will be formed. It is necessary to keep the cut open to induce growth. Place a layer of the fine soil two inches thick under the shoot, and then peg the latter down on to this layer, placing the pin just below the point where the cut was made. If correctly pegged down, the shoot should be in an upright position. Next cover the stem of the shoot thus treated, from the junction with the old plant up to the leaves which were allowed to remain, with another two inches of the soil and make the latter moderately firm. Give gentle watering during dry weather. It will be found that roots will be emitted from the tongue in about three weeks, and the shoot will be ready for severing from the old plant at the end of the following September or early October.

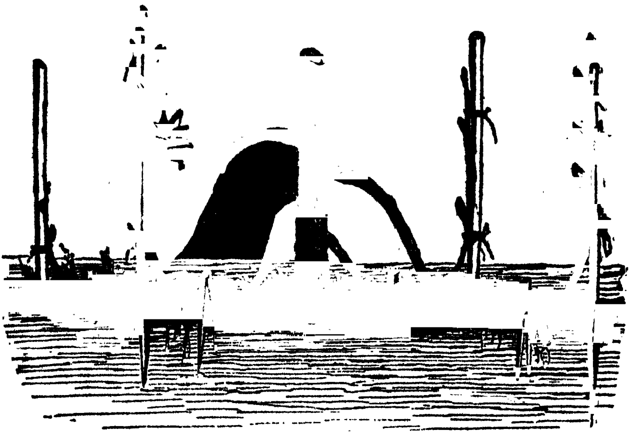


Fig. 591.—Layering.

In the case of shrubs layering is usually done during the winter months, and shoots of the current year are selected, as in the case of hard-wooded cuttings already described. The layers of these are allowed to remain attached to the old plant all the following summer, and then removed during the autumn or winter. A cut is made in the under side of each shoot precisely as advised for carnations, but it should be two inches long instead of one inch.

Strawberries are almost entirely propagated by layering, but here the process is somewhat different. We have already seen in an earlier part of this book that the strawberry plant reproduces itself naturally by means of runners—in itself a vegetative process. The student will remember that during the early summer "wires" are produced, and these bear small plants at various points of their growth. These young plants, produced from a fertile parent, are pegged on to pots of prepared soil, squares of turf, or even to the surface of the strawberry bed. If the soil to which they are secured is kept moist, roots are quickly formed, when the runner or "wire" may be cut and the new plant transferred to where it is required. It should be noticed that although one "wire" will thus produce several young plants, it is found in practice unwise to take more than one from each. Pinch off the tip of the runner an inch or two beyond the plantlet selected. In the multiple layering of trees or shrubs a branch is laid down from the parent stem, horizontally in a trench. If properly treated this branch will form a number of young herbaceous branchlets about three or four inches long, each of which will take root and in the autumn may be cut away as described above.

(iii.) BUDDING is a more complicated system of propagation than any we have yet dealt with, but once grasped the operation is very simple. Roses are propagated very extensively by this means.

The process consists in the insertion of a dormant bud of the variety it is desired to perpetuate into a shoot of a suitable stock or parent. It has been found that many roses do better when thus treated, than they do when grown on their own roots. The two stocks most commonly used are (i.) the wild briar or dog rose; and (ii.) a rose species known as Manetti. The former is used for standard trees and the latter for bush roses.

Stocks of the briar can often be obtained from country hedges during the winter. Those with a fairly young straight stem of about four feet in length should be selected. Secure as many roots as possible with each, and plant them in some rather heavy soil, cutting the tops back to a good plump bud about three feet six inches or three feet nine inches from the soil surface. If all goes well the buds will burst and grow into vigorous shoots by the end of July, when they will be ready for the insertion of the rose buds.

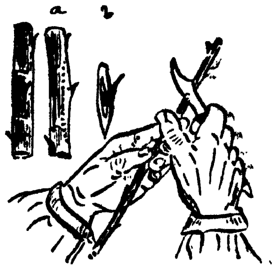


Fig. 592.—Removing the Bud.

All buds that burst on the stem must be removed as soon as seen, with the exception of the three uppermost, which are left.

A dull damp day is the best for the operation of budding, which should be performed as quickly as possible. Some broad strands of raffia, a small sharp budding knife, and a pail containing some damp moss or hay, in which to keep the rose shoots containing the buds, is all that will be required.

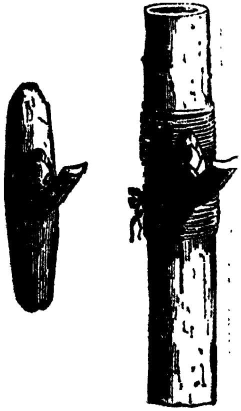


Fig. 593.—Budding.

The best buds will be the rather small ones found on the young shoots that have flowered. Insert the edge of the knife half an inch *above* the bud, cutting just down to the pith, then bring it down under the bud and out about half an inch below it. The shoot should be held in the left hand as shown in the illustration. (Fig. 592.) The path of cutting is indicated by a dotted line in Fig 592A, and the severed bud is also shown (Fig.

592B) clean cut at both ends. If the operation is properly done we shall have a bud with a strip of wood and bark about one-third of the thickness of the shoot. This completes a very important part of the process. A good and practical plan now is to just hold the bud gently between the lips and quickly finish the preparation of the stock. This stock must have been previously prepared by removing all spines from the young shoots, at the point where the bud is to be inserted, *i.e.* close up to the old stem. A longitudinal cut is made in the upper surface of the shoot about 1¼ inches long and close to the main stem of the stock, and then another cut at right angles to the first one, and at the end farthest away from the old wood. This forms a T shaped incision, as shown in Fig. 593.

Sometimes when the bud to be grafted is rather large for the diameter of the stock shoot, the former will not be properly held in the incision unless it is made in the form of a cross, thus +. This is not used often in the case of roses, neither is the ⊥ shaped incision which becomes necessary when there is the danger of a superabundance of fluid killing the bud, as in the case of maples and orange trees. Whatever the shape of the incision, the bark is carefully raised with the handle of the knife (Fig. 594) and then the small piece of bark containing the bud is inserted under the bark of the stock shoot, making sure, of course, that the bud points in an outward direction.

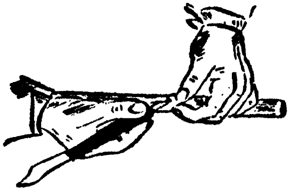


Fig. 594.—Opening the bark for the insertion of the Bud.

With the strands of raffia evenly and firmly bind up the wound, taking care to leave the bud uncovered.

If the bud is fresh and green in three weeks from the date of insertion a union will have been made and the tie must be loosened, but not yet removed. The bud will be best if it remains dormant until the following spring.

Manetti stocks are budded close to the ground, but the operation is precisely the same, except that the bud is inserted in the main stem instead of in the lateral shoots.

If the student has not the opportunity of taking up a short course in this part of the work, such as one of those organised by some of the county education authorities (see page 358), it will well repay him to get a lesson or two from someone who is already initiated into the art.

It need hardly be mentioned here that budding forms a part of the far more extensive art of grafting, which may be defined as the operation of uniting a plant, or portion of a plant—a scion—to another which will support it and furnish it with necessary nourishment until it becomes a part of itself. (Fig. 595).

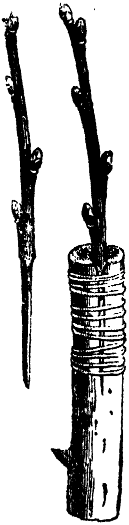


Fig. 595.—Cleft Grafting.

It is indeed interesting and instructive to notice Shakespeare's reference to the art of grafting and budding—

"You see, sweet maid, we marry
A gentle scion to the wildest stock
And make conceive a bark of baser kind
By bud of nobler race; this is an art
Which does mend nature; change it
rather, but
The art itself is nature."

The objects of grafting may be here stated :—

1. To change the character of the plant so that the wood, foliage or fruit becomes modified.
2. To "revitalise" an old or defective tree by the transfusion of younger sap.
3. To increase the foliage, flowers and fruit.
4. To preserve and propagate plants for ornament and use which could not be improved and reproduced in any other way.

As there are about thirty or forty methods of grafting, combinations of the various necessary operations, the student is referred to one of the standard works upon the subject, or to one of our few schools of horticulture, when he can combine the theory with actual and essential practice. (See also "Scheme of Practical Horticulture," Demonstration V.)

2. **Propagation by Corms and Bulbs.**—In an early part of the book we have considered the structure of corms and bulbs in fair detail (see Chapter xi.). The difference between

the two has to be borne in mind when their propagation is desired.

The gladiolus may be taken as a typical plant with a corm, and a description of the propagation of this will equally well apply to all corm-bearing plants.

The gladiolus is capable of reproducing itself in three different ways, *viz.*—

(i.) By seeds;

(ii.) By new corms;

(iii.) By tiny cormlets, termed spawn.

(i.) Seeds are generally employed when new varieties are being sought. These seeds, as we have seen, are the result of sexual processes, and are capable of being influenced by cross fertilisation.

(ii.) The new corms and spawn are vegetative means of reproduction, and are the ones that concern us most here. There is also an artificial system of propagation, and this is by the division of the corms. With a sharp clean knife the corm may be divided longitudinally into three portions, each having an eye or bud. Dust the cut surfaces with finely-powdered charcoal. Allow the portions to dry for a few hours and then plant them in very sandy soil. This operation will, of course, be performed at planting time in the spring. Flowers will not be produced from these cut portions during the summer following planting, and the system is not advised except where a quick increase of any given variety is specially desired.

(iii.) It will be remembered that when the new corm is produced on the top of the old one which dies, sometimes two new ones are formed. The cormlets or spawn are produced at the bases of the larger corms. They may be collected and sown in the spring, in beds of rather sandy soil. They are removed or "lifted" from the soil annually, the same as older plants, and attain the flowering size in three or four years.

Bulbs generally have two natural means of reproducing themselves, *viz.*—

(i.) By seeds;

(ii.) By offsets.

Here, again, in practice seeds are not usually employed, except for raising new sorts (Hybridisation), as the plants which spring from them take a long time to reach the flowering size. Offsets may readily be produced on most bulbous flowers, such as narcissi, tulips and lilies. All that is needed is to remove them while the plants are dormant. In addition to seeds and offsets some lilies produce young bulblets on their flowering stems, and these may be taken off and treated in the same way as that advised for gladiolus spawn. Besides these natural means some bulbs lend themselves to artificial propagation, the lily being a good example. The loose fleshy scales of the bulb are taken off while it is in a dormant condition, and these are inserted to half their depth in extra well-drained pots of sandy soil. The pots are then placed in cold frames, and if very carefully watered, in time the scales will produce a tiny bulb at each base. These little bulbs may be developed as advised in the case of gladiolus spawn.

SUMMARY.

Gardeners find it desirable to adopt artifical and vegetative means of reproduction, viz. by (i.) Cuttings, (ii.) Layering, (iii.) Budding, (iv.) Grafting.

(i.) Cuttings are portions of young wood taken from the old plant. There are soft-wooded and hard-wooded cuttings which are treated in somewhat different ways.

(ii.) Layering enables a shoot to become rooted before it is severed from the parent stem. Carnations are often propagated in this way after they have finished flowering. The layering of shrubs is done during the winter months, and the layers remain attached to the old plant all the following summer. Strawberry plants are often reproduced by layering.

(iii.) Budding consists in the insertion of a dormant bud into a shoot of a stock. Roses are often propagated in this way. Wild briar (dog rose) and Manetti form the best stocks—they may be obtained from country hedges. A plump bud with a little piece of bark attached is inserted under the bark of the chosen shoot. The bark is cut and raised, the bud inserted and the whole bound up with raffia.

(iv.) Grafting has a wide application. It consists of uniting a scion to a stock which :—

1. Changes the character of the plant ;
2. Revitalises the old plant ;
3. Increases the foliage, flowers and fruit.

Propagation by Corms and Bulbs.—The gladiolus reproduces itself by:—

(i.) Seeds, (ii.) New Corms, (iii.) Spawn.

The corms and bulbs may be cut into pieces, each of which will produce a new plant.

Bulbs reproduce themselves by:—

(i.) Seeds, (ii.) Offsets.

The outer scales of lily bulbs will produce new plants from small bulbs, which are formed at the base of the scales.

A Scheme of Practical Horticulture.

[Many of the County Education Authorities have organised excellent Schools of Agriculture and Horticulture. Some years ago, at the request of the **Essex County Council,** *Mr. John Fraser, F.L.S., Editor of the "Gardening World," gave a course of most valuable demonstrations in Practical Horticulture. The mornings of each day were devoted to the study of the Science underlying the practice, while the afternoons were taken up in demonstration lessons in the practice itself. The following Instructions are printed from the notes given on that occasion, for which we beg to repeat the expression of our best thanks, both to Mr. Fraser and Mr. David Houston, F.L.S., the organiser, as well as to the* **Essex County Council.**]

Demonstration I.

THE SOIL AND ITS PREPARATION.

1. **Preparation of land for the growth of crops, and practice in the use of implements.**

(*a*) Garden ground should be trenched every second or third year; part of this should be accomplished every year.

(*b*) Take out a trench 2 ft. wide and 18 in. to 2 ft. deep.

(*c*) Wheel the soil, as it is taken out, to the far end of the quarter to be trenched.

(*d*) Cut the two sides of the trench perpendicularly as the work proceeds, so that no hard ridges may be left to retain water as in a trough in winter.

(*e*) Fork or pick up the bottom of the trench so that the subsoil may be loose and allow superfluous moisture to drain away.

(*f*) If the ground is intended for deep-rooting carrots or parsnips, put a layer of farm-yard manure in the bottom of the trench.

(*g*) For other crops, especially shallow-rooting ones, more manure should be placed in a layer about 9 in. to 12 in. from the surface.

(*h*) Dig the soil of the second trench into the first, and repeat the operation till all the trenches are turned over.

(*i*) Fill the last trench with the soil taken from the first.

2. Rolling.

(*a*) Roll the garden walks to make them smooth and firm.

(*b*) In dry weather it will be necessary to water the walks thoroughly about an hour previously to rolling them, to render them soft, otherwise rolling will have no effect.

(*c*) Roll the grass lawns to render them firm and smooth, and to destroy worm-casts.

3. Practice in the use of the rake, and preparation of seed beds.

(*a*) Level a piece of ground, breaking the clods and raking off the stones with as little soil as possible.

(*b*) Make the surface smooth and ready for seed sowing.

(*c*) Rake off the weeds from ground that has just been hoed, clearing them thoroughly of soil.

(*d*) Wheel the weeds to one rubbish heap, and the stones to another.

4. Practice in the use of the Dutch hoe.

(*a*) Push the hoe through the soil about ½ in. to 1 in. below the surface, so as to cut the roots of all weeds.

(*b*) In doing so, be careful not to cut or injure the cultivated plants.

(*c*) Hoeing is also intended to loosen the surface of the soil amongst all growing crops, especially in dry weather, every part should therefore be equally loosened.

DEMONSTRATION II.

MANURES AND THEIR USE.

1. Farmyard manure.

(*a*) Preparations for the fermentation of fresh farmyard manure.

(*b*) With a steel fork, shake up the manure loosely, piling it up into a conical heap.

(*c*) Let it lie for four to six days, according to the rate at which it heats.

(*d*) Should it be very dry, give it a watering with a rosed watering pot as the work proceeds. This will assist it to ferment regularly and equally, and prevent violent heating and loss of nitrogen in the form of ammonia.

(*e*) After four to six days, when the heap has partly subsided, shake it up in a fresh heap, with the rank manure in the centre.

(*f*) After a few more days it will be fit for the making of hot beds and mushroom beds.

2. Sampling different kinds of artificial manures.

(*a*) Note the colour and general character of guano.

(*b*) If it smells unusually strong, it is losing nitrogen in the form of ammonia.

(*c*) It should always be kept as dry as possible, to prevent loss until about to be used.

(*d*) Note general character of sulphate of ammonium.

(*e*) If in its crystallised form, it is a highly concentrated manure containing about 20 per cent. of nitrogen.

(*f*) Nitrate of sodium is also in the form of crystals, and contains about 15 per cent. of nitrogen.

(*g*) Compare coarse and finely-crushed bones and bone meal.

(*h*) Examine the ground phosphates; ascertain and remember the difference between them and superphosphate.

(*i*) Superphosphate has been prepared by treating the original substances with sulphuric acid.

(*j*) Coprolites and bones are largely used for the making of superphosphate.

(*k*) The best superphosphates are made from phosphatic guanos.

(*l*) Note the general character of potassium salt, known as kainite, and compare with nitrate of sodium, &c.

3. Preparation of liquid manures.

(*a*) Get some pure cow-dung, put it in a tank, and fill up with water.

(*b*) Let it stand for a day or two, cover with a guano bag to prevent the manure from rising, while drawing off the liquid for use.

(*c*) Dilute it with water according to its strength, until of a pale brown colour and relatively weak.

(*d*) Water pot-plants with it every second or third day, and with clear water on alternate days, if necessary.

(*e*) Place a bag of soot in a tank of water, and after 24 hours the clear liquid may be used as a stimulant. Soot contains a small quantity of ammonia.

(*f*) Another liquid manure may be made by putting a handful of guano into four to six gallons of water.

(*g*) Use it weak rather than strong, and alternately with the liquid from cow-manure.

DEMONSTRATION III.

PRELIMINARY CULTURAL OPERATIONS.

1. Seed sowing—vegetables.

(*a*) Prepare a compost of two parts of loam, one part leaf mould, and half-a-part of sand; mix the whole thoroughly.

(*b*) Get some seed-pans and drain them carefully; cover the drainage with the rough siftings of the compost.

(*c*) Fill the pans with the compost; press it down evenly and firmly, finally making the surface perfectly smooth and level.

(*d*) If the soil is relatively dry, give a good watering through a fine rose, and allow the superfluous moisture to drain away.

(*e*) Sow seeds of lettuce or onions, evenly and rather thinly all over the surface.

(*f*) Cover the seeds with a shallow layer (⅛ in.) of a finer and more sandy portion of the compost.

(*g*) Give a light sprinkling of water to settle the compost.

(*h*) Stand the seed-pans in a greenhouse, and keep a daily record of the temperature and the date of the first appearance of the seedlings.

2. Transplanting seedlings.

(*a*) Transplant the seedlings about 1½ in. to 2 in. apart each way into other seed-pans or boxes before they get crowded. Carefully lift with all the roots intact.

(*b*) The distance between the seedlings may vary according to the natural vigour and size of the kind, and the time they are to remain in the boxes.

(*c*) Return the boxes to the greenhouse pit or frame, and place on a shelf or bench near the glass to prevent the seedlings from getting drawn.

3. Planting trees or bushes.

(*a*) Lift evergreens with a ball of soil proportionate to the size of the plants.

(*b*) Previous to lifting, take out holes of sufficient depth and width to take all the roots when spread out.

(*c*) Deciduous trees and shrubs, when lifted in autumn and winter, need not have soil attached, unless of large size.

(*d*) Cover the roots (1) with the finer soil, (2) with rougher material; (3) tread firmly when the holes are about half full; (4) give a good watering, and leave them till the water drains away.

(*e*) Finally fill up the holes and tread firmly.

(*f*) Stake the trees, if necessary, to guard against wind.

4. Mixing composts.

(*a*) Make up a compost of three-parts fibrous loam, half-a-part each of leaf mould and well-decayed cow manure with a good sprinkling of sand. This will suit Pelargoniums and other plants of similar character. Break up the loam roughly by hand, and do not sift any portion of it.

(*b*) For Fuchsias, more sand should be used. The compost in this case should be light and rich.

(*c*) Make up a compost of equal portions of loam and peat, with half-a-part of sand. This would answer for many ferns.

5. Potting.

(*a*) Drain the pots well, according to size, covering the drainage with moss.

(*b*) Put a little soil in the bottom of the pots.

(*c*) Turn out your plant, remove the crocks and the looser portions of the old soil.

(*d*) Pot firmly, and afterwards give a watering with a rosed watering pot.

6. Staking.

(*a*) Stake various plants neatly and effectively, using stakes proportioned to the size of the same.

DEMONSTRATION IV.

VEGETABLE CULTURE.

1. Making sets of Potatoes.

(*a*) It is not advisable to cut "round Potatoes" when only 1 in. to 1¼ in. in diameter, nor "kidneys" unless more than 2 in. long.

(*b*) The eyes at the apex of the Potato are always the strongest, and one of them should be secured in as many cases as possible for each set.

(*c*) For the sets obtained from the basal end of the Potato, select the strongest eyes.

(*d*) Cut the "kidneys" longitudinally, so as to get a good-sized piece of the tuber for each eye.

(*e*) Never cut too close beneath the eye of any set, lest the bud should be deprived of proper nourishment.

(*f*) Relatively large sets are better than small ones.

2. Preparing a seed-bed for Onions.

(*a*) With a fork, level the surface of the ground, if it has been laid up in ridges for the winter.

(*b*) Give a top-dressing of pigeon's or fowl's dung and soot, forking it lightly into the surface.

(*c*) Tread the soil all over, firmly and evenly, with the feet, or roll it to effect the same purpose.

(*d*) Mark off the ground at each end with pegs 12 in. apart.

(*e*) Stretch a line from peg to peg along the ground, and with a draw-hoe take out trenches half-an-inch in depth, and along the size of the line which is used as a guide.

(*f*) After all the trenches have been taken out, sow the Onion seed, thinly and evenly.

(*g*) With the back of the rake, fill in the trenches, beating down the soil lightly with the same.

(*h*) Rake the ground smooth along the lines (not across them), so that no clods or stones may obstruct the germination of the seeds.

3. Sowing Peas.

(*a*) Ascertain the height of the Peas to be sown, and if it be 3 ft., mark off the ground in lines at least 2½ ft. apart.

(*b*) Stretch a line from peg to peg along the ground, and with a draw-hoe take out trenches 3 in. deep.

(*c*) Sow the Peas evenly and moderately thickly along the trenches.

(*d*) With the rake, fill in the trenches till the soil forms a slight ridge above the Peas. Leave the soil rough, as raking is unnecessary with this crop.

4. Sowing Beans.

(*a*) Peg off the ground in lines 3 ft. to 5 ft. apart, according to the height of the Beans to be sown.

(*b*) Take out trenches 3 in. deep, and the full width of the hoe.

(*c*) Sow or plant the Beans in a double row, placing the seeds 6 in. to 1 foot apart in the lines, and alternately with those of the companion line.

DEMONSTRATION V.

PROPAGATION OF PLANTS.

1. Making cuttings.

(*a*) Make cuttings of Gooseberries of young shoots of medium strength and 12 in. to 14 in. long. If longer than this, reduce them by cutting off a part of the apex.

(*b*) Carefully cut away or remove all the buds except four at the upper end. This will prevent suckers and secure a clean stem.

(*c*) Prepare cuttings of Red and White Currants precisely in the same way.

(*d*) Make cuttings of Black Currants about 12 in. in length. None of the buds should be removed, as suckers in this case are desirable.

(*e*) Plant the cuttings in trenches, covering them to a depth of 5 in., and tread the soil firmly against them.

(*f*) Make cuttings of Carnations and Pinks, each 2 in. to 3 in. long.

(*g*) Cut them horizontally, immediately beneath a joint, with a sharp knife.

(*h*) Remove the lower pair or two of leaves and slightly shorten the rest if they are very long.

(*i*) Treat Pelargoniums in the same way; they may, however, vary from 2 in. to 5 in. in length.

(*j*) Remove Rose cuttings with a small heel of the old wood.

(*k*) For planting outside, they should be 9 in. to 10 in. long. Remove the lower leaves, but not any of the beds.

(*l*) Insert them in trenches 4 in. apart and in lines 12 in. asunder to leave room for hoeing.

(*m*) Put the base of the cuttings 6 in. below the surface; cover with soil and tread firmly.

(*n*) For insertion in pots under glass or in a hothouse, the cuttings need only be 3 in. to 5 in. long.

2 Budding.

(*a*) Bud Roses a little below the surface of the soil, in the case of bushes; and as near the main stem as possible in the case of standards.

(*b*) Make a transverse cut through the bark with the budding knife, and a longitudinal one about 3 in. long.

(*c*) Prepare the bud by inserting the knife a little above it, passing downwards and outwards till a piece of wood and bark half-an-inch in length is removed.

(*d*) Cut off the leaf retaining the petiole (*i.e.* leaf stalk). Carefully remove the wood from the bark, retaining the core of the bud in all cases.

(*e*) Lift the bark of the stock with the thin end of the handle of the budding knife, and slip in the bud beneath the bark so lifted.

(*f*) All these operations should be done as quickly as possible, to prevent injury to the cambium layer by exposure to the air.

(*g*) Bind up the inserted bud with raffia, covering all except the bud.

3. Grafting.

(*a*) Graft Apple, Pear, and other fruit trees about 3 in. above the soil, except in special cases where it is convenient or necessary to work the trees at a higher level.

(*b*) For splice-grafting, cut both stock and scion in a slanting or oblique direction, so that the latter will exactly cover the cut surface of the former. The object is to make the cambium layer of both to coincide.

(*c*) In the case of tongue-grafting, make a notch or a deeper slit in the stock, with a tongue in the scion to correspond to the same.

(*d*) When perfectly fitted, insert the tongue in the notch, and bind stock and scion firmly together with a piece of raffia.

(*e*) Where triangular notch-grafting is intended, take out a triangular groove in the stock, narrowing the notch to a point at the lower end.

(*f*) Cut the scion so that it will accurately fit the groove in the stock.

(*g*) Insert it, and tie up firmly with raffia.

(*h*) Cover the grafts with grafting clay, and that again with moss to keep moist.

4. Layering Carnations and Shrubs.

(*a*) Make up a compost of sandy soil and leaf mould, and spread some of it around the Carnations to be layered.

(*b*) Remove the lower leaves of the shoots to be layered.

(*c*) Pass the blade of the knife inwards at a node, and upwards for half-an-inch or thereby, being careful not to sever the shoot from the parent plant.

(*d*) Peg down the shoots, keeping the tongue or cut open.

(*e*) Cover the layered portions of the shoots with the compost, and give a good watering with the rosed watering pot to settle the soil. Repeat the watering in dry weather until the layers are rooted.

5. Division of herbaceous plants.

(*a*) Take a clump of Iris and clear away the soil from it.

(*b*) With a knife, remove every crown of leaves with a portion of roots to the same.

(*c*) Every portion, thus carefully removed, will form a plant.

(*d*) Hundreds of other herbaceous plants may be treated in the same way, with the smallest possible loss or waste of material.

(*e*) Never use a spade in the division of herbaceous plants of any kind, as it is likely to occasion much loss in the case of valuable and slow-growing plants.

DEMONSTRATION VI.

PRINCIPLES OF FLOWER CULTURE.

1. Potting bulbs.

(*a*) For Hyacinths, select 32-size pots (5½ in. to 6 in.), and drain them carefully, putting moss over the crocks.

(*b*) Prepare a compost of three parts fibrous loam, one part leaf mould, one part well-rotted cow-dung, and a good sprinkling of sand.

(*c*) **Fill the pots loosely till the soil forms a little cone above the rim.**

(*d*) **With the fingers and thumb press the bulb firmly into the soil, then press the latter down firmly and evenly all round; add more compost till within ½ in. of the rim, leaving this space for watering.**

(*e*) The pots may be plunged out of doors in cocoa-nut fibre or coal ashes.

(*f*) Three to five Tulips or Narcissi, according to the vigour of the sorts, may be put in 32-size-pots.

2. Planting bulbs.

(*a*) Level and rake smooth a bed or piece of ground.

(*b*) With a measuring rod, mark it off in lines about 9 in. asunder, and draw shallow furrows as a guide in planting.

(*c*) Place the bulbs in position 6 in. apart, putting Hyacinths in one bed, Tulips in another, and Narcissi in a third.

(*d*) The beds may be edged with Crocuses, or with a dwarf-growing variety of the subjects used for the central portion.

(*e*) With a garden trowel, plant the bulbs 3 in. below the surface, moderately compressing the soil above them.

3. Sowing flower seeds in pans or boxes.

(*a*) Prepare a compost of one part loam, two parts leaf mould, and one part sand. Sift the two former through a fine-meshed sieve, and mix the whole thoroughly together.

(*b*) Carefully drain the seed-pans or boxes, putting moss over the drainage, and then some of the rough siftings.

(*c*) Fill the pans with the compost and press it down firmly, being particularly careful to do so at the sides and corners. Make the surface level.

(*d*) **If the soil is dry, give a good watering with a fine-rosed watering pot. Allow the superfluous moisture to drain away.**

(*e*) **Sow seeds of Stocks or China Asters thinly and evenly over the surface.**

(*f*) Cover them with a thin layer ($\frac{1}{16}$ in. to $\frac{1}{8}$ in.) of the finely-sifted compost, using more sand in it.

(*g*) Give a light watering to settle the compost.

(*h*) Prepare some pans in the same way for Begonias or Lobelias.

(*i*) Sow the small seeds very carefully, thinly and evenly over the surface, and give a thin sprinkling of sandy compost to keep the seeds in position.

(*j*) Cover the pans with a pane of glass, and shade them till germination takes place.

(*k*) Stand the pans in a greenhouse, and keep a daily record of temperature and the dates of germination.

(*l*) Stocks are very liable to "damping off"; to check the malady transplant immediately this shows itself.

(*m*) Transplant Lobelias and Begonias when the cotyledons are fully developed, or when the first leaf is formed.

(*n*) China Asters, Marigolds, &c., may be larger before the operation is effected, and require to be 2 in. apart each way for their development.

(*o*) Return the pans and boxes to the greenhouse.

4. Potting seedlings.

(*a*) Get a number of thumb-pots, and put one crock in each, with a small quantity of rough siftings.

(*b*) With a peg carefully lift the seedlings with all their roots intact.

(*c*) Put a little soil in each pot; then, holding the seedling in position with the left hand, fill in the compost with the right, and press moderately firm.

(*d*) Water the plants with the rosed watering pot, and return them to the greenhouse.

5. Bedding.

(*a*) Unless recently dug, fork up the soil, breaking it with the tool.

(*b*) Make the surface smooth and level.

(*c*) Mark off the bed in lines about 12 in. apart. The outer line may be 6 in. from the edge of the bed, and another 6 in. inwards from the former, so as to make a double edging.

(*d*) Lay out a sufficient number of Pelargoniums to fill the centre of the bed at 10 in. to 12 in. from plant to plant.

(*e*) Plant them rather deeply with a garden trowel.

(*f*) Proceed in the same way with the edgings, spacing the plants 6 in. apart. Those in one line should alternate with those of the other.

DEMONSTRATION VII.

FRUIT CULTURE.

1. Visit to a fruit-farm.

(*a*) Note the distances between the different kinds of trees.

(*b*) When bush fruits or vegetables are grown beneath the fruit trees, it is termed double cropping. Note the kinds and system of planting.

(*c*) Observe the methods of pruning the trees.

(*d*) Standard Apples, Pears and Plums, etc., are pruned chiefly in the early stages to form a well-balanced head to the trees.

(*e*) The after-pruning consists chiefly in cutting out the useless shoots, those that cross one another, and dead wood. The object of this is to keep the head of the trees so thinned as to admit air and light for the proper maturation of the foliage, wood and fruit.

DEMONSTRATION VIII.

WORK UNDER GLASS.

1. Making vine eyes.

(*a*) Take a vine-shoot and cut it into lengths of 1½ in. to 2 in.

(*b*) Each piece should possess a bud towards the upper end. This, of course, is regulated by the position of the cuts made.

(c) Drain and fill some large thumb-pots with sandy loam.

(d) Insert an eye in the centre of each pot with the bud just appearing above the soil, which should be firmly pressed down and around the short cuttings or eyes.

(e) Plunge the pots to the rim in a hot-bed, and water them with a rosed watering pot.

2. Visit to fruit-houses.

(a) Observe the stage of the vines and the treatment given in the matter of ventilation, syringing, temperature, stopping, etc.

(b) In the Peach-house, observe and note the same routine of treatment.

(c) Note the removal of lateral shoots from Tomatoes, and the treatment given at the present stage.

Appendix

Date.	Height of B.	Rainfall.			Humidity.	Wind.			Temperature.		Seeds planted	Plants appear above ground.	Remarks on Vegetation.
		Depth in inches.	Character of fall.	Duration of fall.	No. of degrees difference between wet and dry bulb.	Direction.	Duration	Character.	Air.	Soil.			

Appendix K.

A. INSECT AND OTHER PESTS IN FARM AND GARDEN.

B. FUNGOID DISEASES OF PLANTS.

The first part headed *A* is intended to be little more than a summary of the Common Pests which all too often infest Farm and Garden crops, and to which some reference has already been made in the text. We have also referred to certain fungoid diseases, such as clubbing. These are considered in fuller detail in the second part headed *B*.

The Board of Agriculture and Fisheries has published a series of Leaflets dealing with the Pests and Diseases of Plants. These Leaflets are now bound up into sections, which are supplied upon application to the Secretary of the Board of Agriculture and Fisheries, 4, Whitehall Place, London, S.W., for the nominal sum of 1d. each. The information contained in these Pamphlets will prove most valuable to the student as well as to those practically engaged in farming and gardening. Section 9 deals with the pests of field and garden. Section 10 discusses in a similar manner, "Insect and other Pests injurious to fruit trees and bushes," while sections 11 and 12 deal with the Fungoid diseases of plants. We beg to express our best thanks to the Board of Agriculture and Fisheries, as well as to His Majesty's Stationery Office, for their kind permission to reproduce here many of the illustrations used in the above-mentioned Leaflets.

A. Pests in Garden and Field.

It will be seen in the following summary that most of the Pests are Insects. Now Insects, as a rule, undergo what is known as metamorphosis, generally passing through three stages of varying duration. The life history of an Insect may be well studied in the Moth Butterfly or Bee. The eggs are laid in some more or less secure place. and when hatched give birth to the GRUB, LARVA, or CATERPILLAR. This is the first or feeding stage. After existing in this active form for some time the grub passes into the PUPA, COCOON, or CHRYSALIS form. This is the second or resting stage. In due course the MATURE INSECT is developed from the apparently quiescent pupa This is the third, or what is sometimes called the reproductive stage of the creature. It will be noticed that it is the first—grub, larva, or caterpillar—stage when the insect is most harmful to farm or garden crops; although, in the case of many flies and beetles, much damage is done during the third, mature stage. The Student should especially note in the life history of the Pests, the stages during which they are so harmful, whether the first or third stages of their existence, or both.

Moths, Butterflies, Beetles, Bees, and most Flies undergo changes as indicated above. Other Insects, such as Grasshoppers, Locusts, Bugs, and Dragon flies undergo a less perfect series of changes, the grub or larva resembling more or less the mature insect. A few kinds, chiefly Lice, do not pass through any metamorphosis, but emerge from the egg in a mature form and condition.

I. Worms.—(i.) WIREWORMS:—These represent the larval stage of Click Beetles or Skip-jacks, which are to be found under stones, at the roots of grasses, upon grasses, flowers and trees, in the hedges and fields.

Wireworms are very destructive because:

(*a*) They attack most crops.

(*b*) They feed on stems and roots, except during times of severe frost.

(*c*) They live for more than three years in the wireworm form.

PREVENTION AND REMEDY.—The student is referred to the leaflets of the Board of Agriculture for fuller details.

1. By trapping the Click Beetles and larva. How?
2. By using "Vaporite," which smells of Naphthalene.
3. By drilling ordinary superphosphate, or a mixture of manure containing superphosphate with the seed.

4. By using stimulating manures when the crop is first attacked.

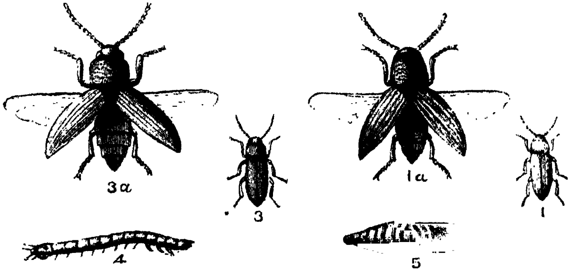
5. By penning sheep on clover land before a deep and thorough ploughing.

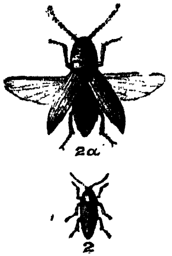
6. By turning fowls on the land during the ploughing, when portable fowl houses are placed on the infested land.

7. In the garden, by using bi-sulphide of carbon.

8. No remedy or preventative, however, can replace clean farming and suitable manuring.

Caution.—Gas lime, lime, salt, mustard and rape dust are poor, if not utterly worthless, remedies for the extermination of wireworms.





1 and 1*a*. *Agriotes lineatus*
2 and 2*a*. *Agriotes sputator*. } (Natural size and magnified.)
3 and 3*a*. *Agriotes obscurus*.

4. Larva of *Agriotes lineatus*. } (Natural size.)
5. Pupa.

(ii.) THE STEM EELWORM.—These attack the stems of wheat, oats, clover, lucerne, beans, onions and some grasses. They give rise to matted and swollen (often bulbous) roots. In cereals they damage the plant and prevent the production of grain bearing stems. In infested onion plants the leaves become thick and twisted, and in all cases the growth is seriously checked.

PREVENTION AND REMEDY.—

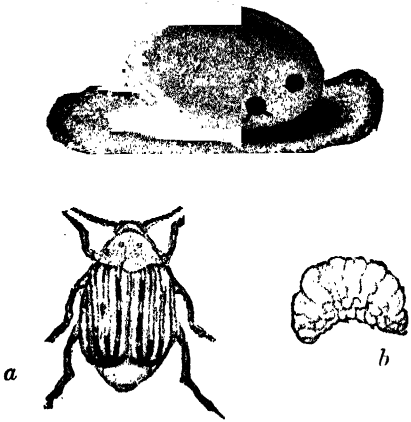
1. By adopting a suitable rotation of crops.
2. By destroying the refuse of infested crops.
3. By deep ploughing in the field and trenching in the garden.
4. By suitable manuring and dressing with sulphate of potash and sulphate of ammonia.

For earthworms, see Darwin's famous work.

II. **Beetles.**—(i.) PEA AND BEAN BEETLES (*Bruchus and Sitones*).—Some species of Bruchus attack peas *only*, but Sitones, commonly known as the Pea and Bean Weevils, will infest both plants. The mature Weevils eat the leaves of the young shoots, and the larvæ devour the roots. In the case of Bruchus it is the grub (or larva) which is the real cause of damage, for it lives in the vital part of the seed and prevents germination.

The Striped Pea and Bean Weevil (*Sitones lineatus*).
1. Natural size. 2. Magnified.

3. The Pea Beetle (*Bruchus pisi*), × 5 (after Curtis).



a. The Bean Beetle (*Bruchus rafimanus*), × 5. *b*. Larva, × 5.
c. Bean showing issuing beetle.

PREVENTION AND REMEDY.—

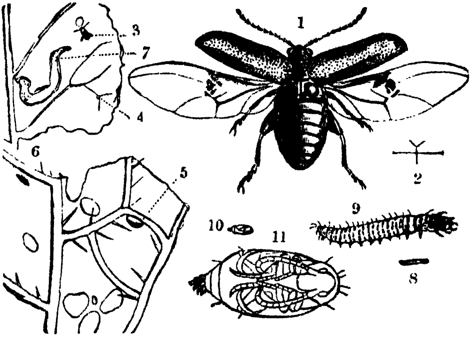
1. Peas attacked with Bruchus should not be sown.
2. By fumigating the peas or beans with bisulphide of carbon.
3. By keeping the seeds (unsown) for a season.
4. Where Weevils have attacked the plants, lime or soot, or a mixture of both, may be sprinkled over the plants after rain. Powdered guano is recommended also.
5. By spraying the plants with arsenical washes, also with weak mixtures of paraffin and water.
6. Attacks are sometimes prevented by a thorough rolling after a dressing of soot and lime.
7. By summer fallowing and burning of stubble, weeds, roots and rubbish.

(ii.) "FLEA" BEETLES (or TURNIP FLY).—These attack every kind of crop, especially turnips, swedes, rape, kale, cabbage, and other cultivated cruciferous plants. The most destructive of these beetles are:

(*a*) The common turnip flea.

(*b*) The cabbage flea.

The latter has been proved to be more harmful than the former, and has at times become quite a general pest in the country. The turnip flea will settle on the young leaves as soon as they show themselves above ground, especially in dry weather. In such seasons several sowings often become necessary, because the whole crop has been cleared off. In the case of the cabbage flea, mature plants may be entirely destroyed by becoming infested. Both these insects are quite small, being between one-eighth and one-tenth of an inch in length; the larvæ, however, are about twice as long.



1, The Turnip Flea Beetle, much magnified; 2, nat. length and wing expanse; 3, nat. size; 4, 5, egg, nat. size and mag.; 6, 7, mine, and cuticle eaten away by larva; 8, 9, larva, nat. size and mag.; 10, 11, pupa, nat. size and mag.

PREVENTION AND REMEDY.—

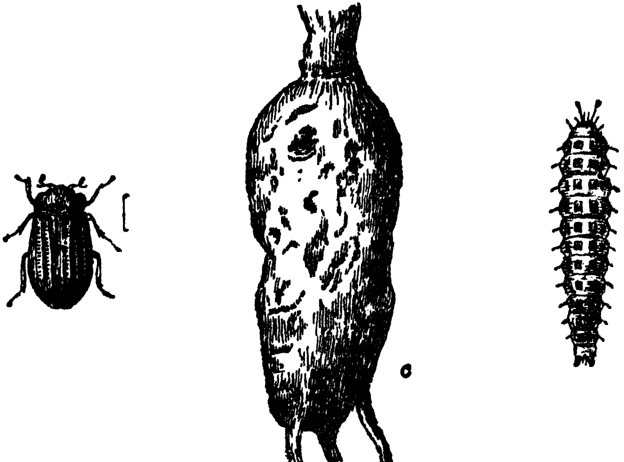
1. By sowing upon a "stale furrow" *i.e.*, on land not freshly ploughed.
2. By rolling the land after drilling, or the young infested plants may be carefully rolled, with good results.
3. By drilling with the seed artificial manure mixed with powdered ashes.
4. By putting in seed with a water drill.
5. By soaking the seed in paraffin or turpentine before sowing it, or by sprinkling small quantities of paraffin oil on the leaves of the seedlings.
6. By destroying the winter homes of the pests. Where?

7. By catching the beetles with a tarred frame. How?
8. By destroying charlock and other cruciferous weeds which supply these pests with food until the turnip plants are ready for them.

Caution.—The old custom of sowing mustard seed with the turnip seed in order to draw off the beetles is of little value when the attack is at all serious.

(iii.) TURNIP MUD BEETLES.—There are several species of these, most of which are aquatic in habit, although capable of flight. They have proved destructive in some parts of Scotland, especially in Aberdeenshire. The harm is done by both beetle and grub, which take up a position in the crown of the "root," sheltered amongst the leaf bases, the young leaves being destroyed as they grow up. The external sign of the disease is the pronounced curling up of the leaves. The bulb itself is often penetrated, and this gives entrance to other enemies. Thus:

(*a*) The leaves may be eaten.
(*b*) The leafstalks may be holed and tunnelled.
(*c*) The swollen "roots" may be gnawed, tunnelled and hollowed out, especially in the upper part.



HELOPHORUS RUGOSUS.—*a*. Beetle, magnified (after Rye). *b*. Larva, magnified (after Ormerod). *c*. Turnip, showing gnawings of grub.

PREVENTION AND REMEDY.—

1. By sowing the turnips as far as possible from the infected area.
2. By dressing the land with Nitrate of Soda.

(iv.) **CHAFER-BEETLES** or **WHITE GRUBS.**—Great damage is done by these pests both in the larval and mature form. The grubs attack the roots, and the beetles the leaves of forest and fruit trees, as well as grass, corn, peas and many vegetables. They are, however, far more common and destructive on the Continent. There are four or five species, easily distinguishable, varying in size from one-half to one inch in length. The grubs of the different beetles, however, are very similar, especially when young. The two most common beetles are:—

(*a*) The large Cockchafer.
(*b*) The Summer-chafer.

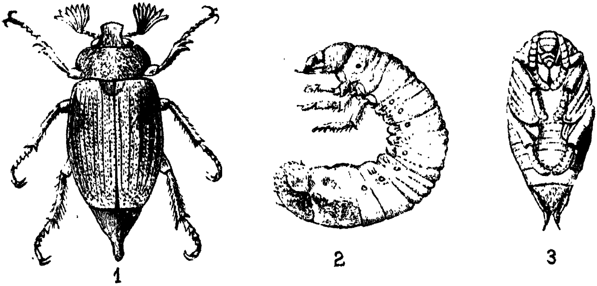


FIG. 1.

THE LARGE COCKCHAFER (*Melolontha vulgaris*).
Perfect insect. 2. Larva. 3. Pupa. All natural size.

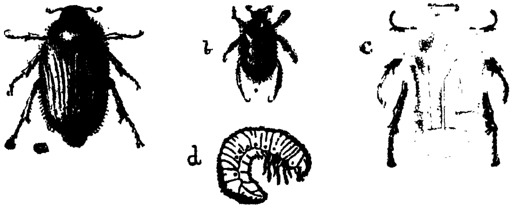


FIG. 2.

The Summer-chafer (*Rhisotrogus solstitialis*). *b*. The Garden-chafer (*Phyllopertha horticola*). *c*. Green Rose-chafer (*Centonia aurata*). *d*. Larva of the Garden-chafer. All natural size.

PREVENTION AND REMEDY.

1. By destroying the beetles found upon the trees in the early summer.
2. By shaking or beating the beetles down on to tarred boards.
3. By trapping the larvæ under turf or dung.
4. By top-dressing the fields with gas-lime or kainite, or similarly treating the garden with soot and lime.
5. By hoeing and hand picking.
6. By encouraging the birds like rooks, starlings, green plovers and gulls, especially at ploughing time.
7. By the scientific method of infecting the chafer larvæ with fungoid disease.

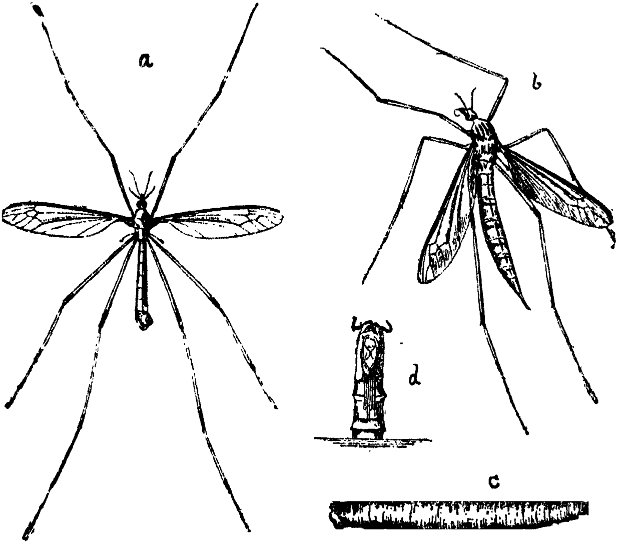
(v.) THE COLORADO BEETLE.—This is often known as the great American potato pest. It is, fortunately, extremely rare in this country. It is interesting to note that, under the Destructive Insects and Pests Order of 1908, notice must at once be given to the Board of Agriculture if one is found.

III. **Flies.**—THE CRANE FLY OR DADDY LONGLEGS.—These insects are frequently very destructive to the various crops of the garden and field. They attack all kinds of corn, grass, turnips, clover, peas, beans, cabbage and garden plants generally. The two common species are (*a*) The Summer Crane Fly; (*b*) The Yellow Spotted Crane Fly. The breeding grounds of these pests are to be found chiefly in hedgerows and ditches, and in low-lying, undrained meadows. They are exceedingly prolific, the female laying as many as 300 eggs, and from time to time many cases of serious damage done by both larva and fly have been recorded.

PREVENTION AND REMEDY.—

1. By keeping ditches clean, the hedgerows well trimmed and the land well drained.
2. By dressing the land with gas-lime before thorough ploughing. A spring dressing of kainite is sometimes recommended (or a mixture of nitrate of soda, manure and soot).

3. By hoeing and hand-picking, thus destroying the grubs or exposing them to the attacks of such birds as starlings, peewits and others.



a. Summer Crane Fly (*Tipula oleracea*). Male, natural size.
b. Female (after Ormerod). *c.* Larva. *d.* Pupa.

Caution.—Late sowing is a somewhat risky preventative, owing to uncertain weather conditions.

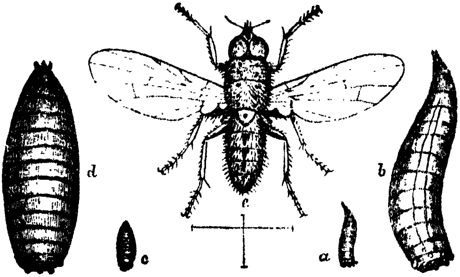
(ii.) The Onion Fly is a most destructive little dark grey creature, with black bristles and red eyes. It has become a serious nuisance in cottage and market gardens, leading to the decay of the entire plant, the bulb becoming quite rotten and useless. The first symptom of attack may be seen in the drooping and flagging of the leaves, which become yellow and sickly. Upon cutting open the swollen bulb of the onion it will be found to be infested with dirty white maggots of about one-third of an inch in length.

Prevention and Remedy.—

1. By spraying the plants with paraffin emulsion.

2. By placing a mixture of sand and paraffin at the base of the onion plant.
3. By sprinkling the onion plant with soot.
4. By dressing and hoeing the land with finely powdered Kainite.
5. By earthing up the onion plant well over the neck of the bulb.
6. By dressing and hoeing the land with a mixture of soot and lime, as in 4 above. Nitrate of Soda may also be used.
7. By growing another crop on the infected land.

Caution.—If only a few plants become infested with the fly, and show the characteristic drooping of the leaves, it is advisable carefully to dig them up at once and destroy them.



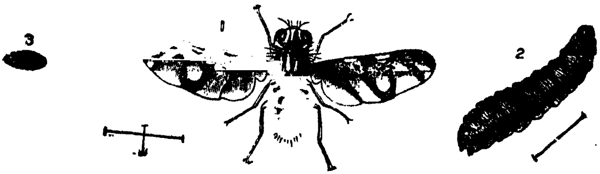
THE ONION FLY (*Phorbia cepetorum*).

a and *b*, Larva, natural size and magnified; *c* and *d*, Pupa, natural size and magnified; *e*, Fly magnified; lines showing wing expanse and length of body.

(iii.) THE CELERY FLY is a tiny insect one-eighth of an inch in length, of a tawny brown or honey yellow colour, which is answerable for much injury to the celery and parsnips in our gardens. The mischief is done by the grub, which makes pits and passages in the leaves, and feeds upon the soft juicy tissues beneath the epidermis, thus causing the leaves to become small, green, and bitter in flavour. The whole plant assumes a withered and shrivelled appearance, and often succumbs to the attack. Parsnips become small, much forked, and irregular in shape.

PREVENTION AND REMEDY.—

1. By careful digging and retrenching.
2. By removing some of the surface soil when it is infected, and then giving a dressing of gas lime.
3. By burning the refuse of preceding crops, or burying it *very* deeply.
4. By keeping down the growth of the common Cotton Thistle in the neighbourhood. Why?
5. By forcing rapid leaf growth by means of nitrate of soda. (See action of nitrates, page 323.)

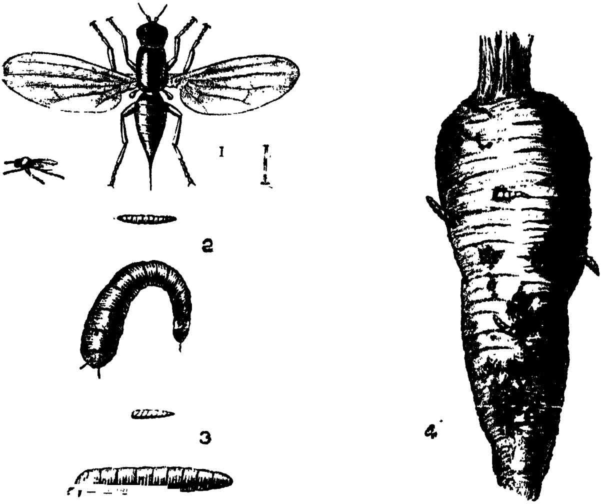


1. Fly magnified. 2. Larva magnified. 3. Pupa, natural size.
Lines showing natural size of Fly and Larva.

6. By applying soot and lime to the plants while the dew is on them, to prevent the flies laying eggs on the stems and leaves.
7. By spraying with a mixture of paraffin and soft soap solution; or weak carbolic acid may take the place of the paraffin.

Caution.—In the last method of treatment the proportion and strength of the materials used is of the highest importance. The leaflets will give this in detail.

(iv.) THE CARROT FLY, which is of a shiny black or dark green appearance, is found in old roots more often than in those which have been pulled for bunching. The maggots of this fly cause the carrots to become brown or "rusty," a preliminary condition to absolute decay. As in the case of the turnip fly (beetle) it is more injurious in dry seasons when the growth of the root is retarded. Frequently, when badly attacked the root becomes grooved and cracked, and the larvæ hide in these crevices. At the same time the foliage of the plant changes colour and turns reddish. In this impoverished state the carrot is often attacked further by millipedes, slugs, and wood-lice.



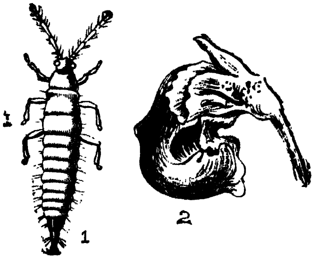
1. Fly, natural size and magnified. 2. Larva, natural size and magnified. 3. Pupa, natural size and magnified. 4. Infested carrot showing "rust" spots.

PREVENTION AND REMEDY.—

1. By immediately removing from the ground those carrots, the tops of which show the characteristic reddening of the leaves.
2. By spraying with paraffin emulsion, *after*—
   (*a*) sowing; (*b*) germination; (*c*) thinning.
3. By drilling the seeds with ashes, sawdust and sand impregnated with paraffin oil.
4. By pressing the earth round the stems or bases of the leaves, and consolidating the earth by watering.
5. By early and deferred sowings.
6. By the proper cleaning, ploughing and trenching of the land.

Caution.—It appears in practice that the thinning-out process considerably weakens the plants, and predisposes them to attacks of the fly. Hence some recommend a thin sowing to obviate the necessity of subsequent thinning out.

(v.) THE BLACK FLY, OR THE PEA AND BEAN THRIP, is another tiny pest of about one-tenth of an inch in length. Although, as the name implies, they generally attack peas and beans, and other leguminous plants, different varieties have been found to infest wheat, onions, and even apples. These insects, like plant lice (described below), have no chrysalis stage. In leguminous plants the flowers are generally first attacked, with the result that the lower petals begin to shrivel, then the upper parts gradually wither and die, until only a little dried-up mass remains, in the place of a healthy flower. It is really astounding the amount of mischief these Black-fly Thrips can do. Kent and Sussex growers have been much troubled by their ravages.



1. THRIPS, much magnified; line showing natural size.
2. Distorted pod.

PREVENTION AND REMEDY.—

1. By destroying all likely winter shelters for them, such as pea and bean sticks, and refuse of any infected crop.
2. By using pyrethrum wash.
3. By liming the ground.

Caution.—Where the flowers of any plant are attacked, spraying is of doubtful efficacy.

(vi.) THE CABBAGE ROOT FLY.—This may be described as a universal pest. It is all too common in our own country as well as on the Continent and in America—United States and Canada. It is very similar in appearance to the house fly, and for this reason it is often very difficult to identify it. There can be no mistake, however, concerning the mischief it is capable of doing. It may be regarded as a general enemy of cruciferous plants. The maggots have been found at their destructive work on the cauliflower, turnip and swede, as well as the radish and broccoli. Even weeds and garden flowers are not free from attack, the symptoms of which are: (*a*) A stunting of growth; (*b*) discolouration and withering of the leaves; (*c*) infested parts become slimy and rotten before they finally succumb.

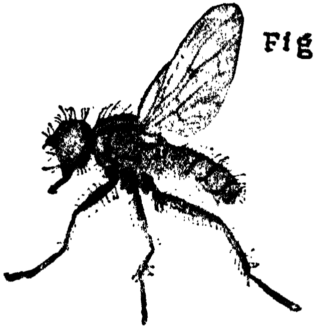


Fig. 1.

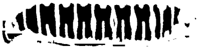


Fig. 2.

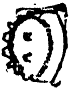


Fig. 3.

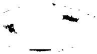


Fig. 4.

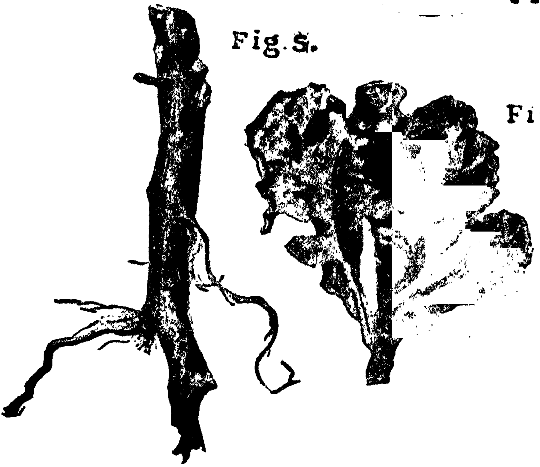


Fig. 5.

Fig. 6.

Fig. 1. Male Fly, greatly magnified. Fig. 2. Maggot, magnified. Fig. 3. Last segment of maggot enlarged, showing tubercles. Fig. 4. Puparium, magnified. (Figs. 1 and 3 after Prof. M. V. Slingerland.) Fig. 5. Part of attacked cabbage, with *Larva in situ*. Fig. 6. Withered leaves of attacked cabbage.

PREVENTION AND REMEDY.—

1. By early sowings.
2. *By protecting cabbages and cauliflowers by means of tarred paper.*
3. By sprinkling paraffined sand once a week round the stems of the cabbages.
4. By picking off the maggots by hand.
5. By burning infested plants.
6. *By the judicious use of insecticides like bisulphide of* carbon and carbolic acid emulsion.
7. By a well ordered rotation and the destruction of all cruciferous weeds in the vicinity.

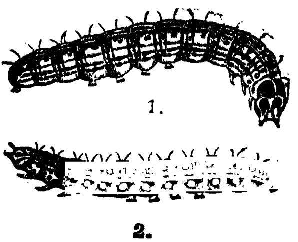
Caution.—Early sowing is a questionable and often disappointing remedy.

IV. **Caterpillars and Moths.**—(i.) SURFACE CATERPILLARS cause serious injury to many crops. Perhaps the most harmful are:

(*a*) The caterpillar of THE TURNIP MOTH.

(*b*) The caterpillar of THE HEART AND DART MOTH.

The Cut-worms of the United States are similar creatures. Young plants may be completely cut through just below the surface of the soil by these pests. Potatoes and other tuberous and bulbous roots are burrowed into and the inside damaged, and even cleared of their contents; or they may become quite rotten, as if they have been attacked by wireworms. Grasses and cereals generally have also been destroyed, while recent reports have recorded alarming damage to cabbage, lettuce, and carrots, as well as other garden plants. Dry weather militates against the depredations of the caterpillars, and a hard winter of alternating frost and thaw tends to clear the fields and gardens of these ubiquitous pests.



1. Caterpillar of the Turnip Moth (*Agrotis segetum*).
2. Caterpillar of the Heart and Dart Moth (*Agrotis exclamationis*).

Prevention and Remedy.—

1. By applying ordinary or gas lime to the infested fields and subsequently ploughing deeply.
2. By exterminating, or at least keeping down the weeds, especially cruciferous weeds.
3. By disturbing the land by horse and hand hoeing, thus crushing the pests or turning them up for the birds.
4. By the application of soot, or a mixture of lime and soot, which probably stimulates the growth of the plants. Kainite is also used.
5. By the early earthing of potatoes.
6. By hand picking at night time.

Caution.—In America the Caterpillars have been destroyed by spraying the plants with Paris green. This is often regarded as a dangerous remedy. Why?

(ii.) The Diamond-back Moth.—The caterpillars of this moth—a little creature of light brown colour shaded with grey, with diamond-shaped marks on its back, and measuring only half an inch long—often causes considerable damage to turnips, swedes, rape, cabbages, and plants of the Brassica group generally. The caterpillar voraciously devours the leaves, perforating them with large holes, leaving only the harder parts of the

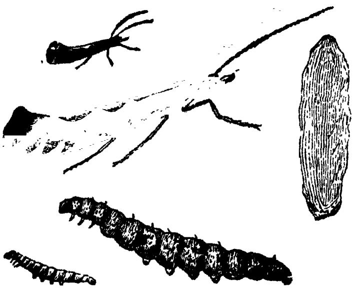


Fig. 1.

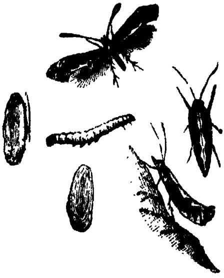


Fig. 2.

Fig. 1. The Moth and Caterpillar, natural size, and magnified; the Cocoon, natural size, and magnified. Fig. 2 Moth flying, natural size; Moths resting, natural size; Caterpillar and Cocoon, natural size.

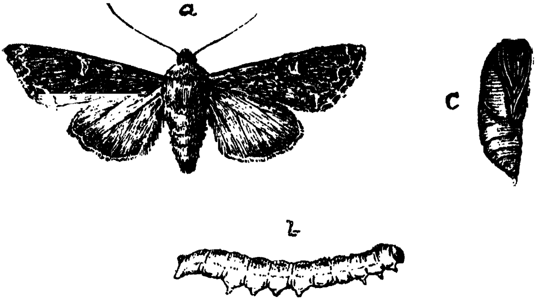
(N.B.—These are two separate blocks of the Board of Agriculture.)

leaves. A field of turnips so infested presents a melancholy sight "when the sun shines upon the riddled and whitened leaves." Great havoc has been wrought by these insects in the Eastern Counties, where whole fields of turnips and cabbages have been cleared by their ravages. The reports have repeatedly stated that the Caterpillars were "clearing all before them.' The Board of Agriculture therefore instituted an exhaustive inquiry, including experiments as to the value of various remedial measures, suggestive and practical. Use was made of the discovered fact that the caterpillars of the Diamond-back Moth were attacked by parasites and destroyed by other insects, so that Stainton, writing some two months after the first note of alarm, said: "Probably the parasites—the natural enemy of the moth—will this year (1891) be developed in such numbers that the pest will be almost annihilated in 1892."

PREVENTION AND REMEDY (from the results of the 1891 enquiry).—

1. By dressing the infested plants with soot and lime.
2. By spraying with carbolic acid and paraffin.
3. By distributing over the land (*a*) soot and lime, or (*b*) soot and sulphur. The latter may also be applied to the plants.
4. By horse-hoeing with branches of birch, broom and furze.
5. By applying nitrate of soda, guano, or other forcing manures.
6. By clearing and cleaning the hedge-rows and ditches.
7. By parasites and other natural enemies, as described above.

(iii.) THE CABBAGE MOTH.—The caterpillar of this moth not only destroys cabbages, but also other plants, such as cauliflowers, lettuces, broccoli, turnips and many flowering plants; in fact, few crops are free from its attack. Both the moths and caterpillars vary much in colour, the latter, when fully grown, have the characteristic habit of rolling themselves up in a ring when touched. They not only eat the green leaves, riddling them through and through, but often spoil the entire plant by their moist green excreta.



a. **Cabbage Moth**; *b*. **Caterpillar**; and *c*. **Pupa** (**all natural size**).

Prevention and Remedy.—

1. By the destruction of the chrysalids when the ground is dug in winter; by turning the poultry on the land.

2. By hand-picking while the caterpillars are attacking the outer leaves.

Caution.—The cabbages may be dusted with old and powdered gas lime, but this treatment renders them less suitable for feeding or cooking purposes.

Plant Lice or Aphides.—These well-known pests have a world-wide occurrence under the different names of Green Fly, Black Fly, Smotherers and Dolphins. The disease they produce is often called the "blight." They attack all forms of Plant Life, whether under glass or in the open air. Like the Pea and Bean Thrips, they undergo incomplete metamorphosis. Plant lice damage the crops in two ways:

(*a*) By sucking the sap from the plant.

(*b*) By interfering with the function of the stomata of the leaf.

Dry hot weather is particularly favourable to the rapid multiplication of aphides, and the plants being in a weak condition at such times, the attacks often prove fatal. The reproduction of plant lice constitutes one of the most fascinating chapters in the history of animal life. It is calculated that a single aphis may, under normal conditions, produce many millions of descendants in one season. Some kinds, as the Rose Aphis, attack the leaves and shoots; others, like the Bean Aphis, destroy the bean pods; while others, like the Woolly Aphis, infest the roots, stems and twigs.

PREVENTION AND REMEDY.—

1. By spraying with a soft soap wash. Quassia is sometimes added to the wash. There is also a special paraffin emulsion, consisting of paraffin, soft soap, and caustic soda. (For proportions, etc., see Leaflet 104.) Both this and Pickering's paraffin emulsion have been used with marked success.
2. For those aphides which attack the root, by injecting into the soil bisulphide of carbon.
3. By encouraging their natural enemies, such as Ladybirds and their larvæ, Hover fly maggots, the larvæ of the Lace Wing, and certain tiny parasites which lay their eggs in the bodies of the plant lice.

Caution.—*Prompt* spraying is most important; the aphides should be attacked as soon as an invasion shows itself.

VI. **Millipedes and Centipedes.**—These pests are allied to insects in structure. They consist of a head, followed by a number of segments bearing two or four legs each; insects have three chief parts, head, thorax, and abdomen, and only six true legs. They are found in damp places, under stones and rotting wood; they are especially attracted by decaying vegetable matter. On the whole, centipedes are useful, while millipedes are harmful. The latter will destroy potatoes and lily buds, and feed upon any young roots available. Some forms, however, are carnivorous in habit. The following contrast is useful:

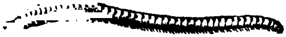


FIG. 1.

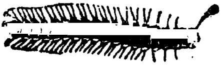


FIG. 2.

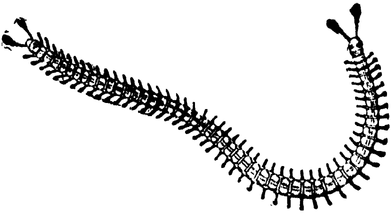


FIG. 3.

Figs. 1 and 2, Millipedes (1, *Julus Pulchellus*; 2, *Polydesmus complanatus*).
Fig. 3, Centipede (*Geophilus subterraneus*).

CENTIPEDES.	MILLIPEDES.
Long antennæ.	Shorter antennæ.
Body flattened.	Body round.
Bases of legs wider apart.	Bases of legs close together.
One pair of legs to each segment.	Two pairs of legs to each seeming segment, except in front four.
Poison claws and glands.	No poison claws.
Active, carnivorous and useful.	Mostly vegetable feeders and distinctly harmful.

PREVENTION AND REMEDY.—

1. By mixing the infested leaf mould with lime.
2. By applying lime and soot-and-water to the land.
3. By trapping them with pieces of hollowed-out mangolds.
4. By injecting bisulphide of carbon into the soil.

Caution.—Poisoned baits are sometimes used, but these are somewhat dangerous.

VII. **Snails and Slugs.**—These are animals of a far higher type than those pests considered above. They are generally of terrestrial habits, and are attracted by all kinds of vegetable matter. Some kinds of slugs, however, will not touch green matter unless there is nothing else for them to eat. Others will feed on cabbage, broccoli, clover, beans, peas, wheat and other cereals, and even young potato shoots, as well as flowering plants. Snails confine themselves to vegetable matter, more particularly to leaves and fruit. There are many varieties of snails, of which the

Wood Snail, Strawberry Snail, and Banded Snail are most common. All are capable of doing much damage.

PREVENTION AND REMEDY.—

1. By improving the drainage.
2. By avoiding the use of manures containing them.
3. By dressing with—
    - (*a*) Soot and lime.
    - (*b*) Salt and lime.
    - (*c*) Caustic soda and lime.
    - (*d*) Powdered coke.
4. By "ringing" round each plant or patch with slaked lime or fine ash soaked in paraffin.
5. By baiting with bran mash or moist oatmeal.
6. By hand-picking and application of soot.
7. By clearing away rockeries, ferneries, etc., in neighbourhood of the crop.
8. By deeply trenching when they are known to come from an infested spot.
9. By giving "entry" and encouragement to ducks, poultry, thrushes, blackbirds, toads, moles, shrew mice, and even centipedes.

The student should endeavour to make a detailed study of the life history of the above pests, at the same time collecting and preserving typical specimens. Few practical exercises we have recommended throughout this book should be fraught with greater interest or scientific usefulness.

SUMMARY.

Pests to Farm and Garden Crops.

I.—WORMS.—(i.) Wireworms; (ii.) Stem Eelworms.

II.—BEETLES.—(i.) Pea and Bean Beetles; (ii.) Flea Beetles or Turnip Flies: (*a*) Turnip Flea, (*b*) Cabbage Flea; (iii.) Turnip Mud Beetles; (iv.) Chafer-beetles or White Grubs: (*a*) Large Cockchafer, (*b*) Summer-chafer; (v.) Colorado Beetle.

III.—FLIES.—(i.) Crane Fly or Daddy Longlegs; (ii.) Onion Fly; (iii.) Celery Fly; (iv.) Carrot Fly; (v.) Black Fly; (vi.) Cabbage Root Fly.

IV.—CATERPILLARS AND MOTHS.—(i.) Surface Caterpillars: (*a*) Turnip Moth, (*b*) Heart and Dart Moth; (ii.) Diamond Back Moth; (iii.) Cabbage Moth.

V.—PLANT LICE OR APHIDES.

VI.—MILLIPEDES AND CENTIPEDES.

VII.—SNAILS AND SLUGS.

B. Fungoid Diseases of Plants.

Introductory.—This book has previously dealt with *green* plants which, by virtue of their green colouring matter—chlorophyll—are capable of manufacturing organic food (sugar, etc.), from carbonic acid gas and water. We now propose to treat briefly a group of non-green plants, termed fungi, which are responsible for many plant diseases.

Fungi, being lacking in chlorophyll, cannot make their own organic food, and thus are compelled to absorb it ready-made; this they do either by living upon other creatures, or upon decaying organic matter.

Structure and Life History.—The fungi are a numerous group, and vary very much among themselves in their life histories and methods of reproduction. We wish here to draw the student's attention to a few salient points in connection with the group generally. A fungus plant usually consists of a tangled mass or *mycelium* of delicate colourless threads called *hyphæ*; these threads ramify in every direction in the nutritive substratum; by their active growth they cause the fungus to spread, and the nourishment they absorb is used in forming the reproductive bodies or *spores*.

Spores differ from seeds in being composed of single cells. They are, consequently, extremely light and minute, and are readily carried about by the air. The fungus plant may produce two kinds of spores: one kind is usually thin walled and capable of instant germination; the other kind being much fewer in number, thick walled, and designed to tide the plant over an adverse period. Sometimes the latter kind of spore is produced as the result of a sexual process. The two kinds of spores are produced as a rule at different times, the thick-walled or resting spores commonly closing the life history of the individual; they also frequently differ in colour, and are thus evident to the naked eye. The gooseberry mildew, for example, produces first a mauve-coloured mass of spores on the leaves of the gooseberry plant, but later it produces black resting spores upon leaves decaying upon the ground. Again, the winter rot disease of potatoes is characterised by white or pink spores in an early stage, and by crimson spores at a later period in its life history. Any spore on germination gives rise to a thread, which is the commencement of a new fungus plant.

Hibernation.—Many fungi pass the winter in the form of resting spores, the thick coats of which enable them to withstand frost easily; this has been proved experimentally in the case of black scab in potatoes. Spores of this and other diseases may remain dormant in the soil for two or more years, and the student will thus realise that the sterilisation of an infected soil is frequently a difficult matter. The spores of smut—a disease attacking cereals—often pass the winter lying in chinks upon the surface of the grain or its investing chaffy scales. In other cases the fungus may remain in the mycelial condition enclosed in bark, dead twigs, fallen leaves or fruit, or in diseased roots or tubers. The sclerotium disease persists within the stems of its host plants in the form of sclerotia—more or less oval, blackish bodies, of varying size, and composed entirely of fungal filaments which are densely matted externally, to form a firm, protective rind.

Scattering of the Spores.—As a general rule the spores are produced terminally upon erect filaments, which project slightly from the surface of the host plant; their exposed positions and extreme lightness offer every facility for distribution. They may be scattered from plant to plant by air currents, as in the gooseberry mildew, or by insects, as sometimes happens in black rot—a common disease amongst plants of the cabbage family. Mites are largely responsible for disseminating the spores of winter rot, as they crawl over the potatoes when stored in pits, etc.

Rain may wash spores produced upon the leaves down to fruit lying below, as in apple scab and the brown rot of fruit; or the spores may be washed into the soil, there to be new centres of infection, as with young tubers lying near the surface of the ground and becoming diseased. A similar scattering of spores sometimes results when infected greenhouse plants are syringed.

The soil may become infected in a variety of ways; the fungus may normally reside in the soil in the event of roots of host plants being absent, and may obtain food from decaying organic matter. It may gain entrance to the soil along with farmyard manure, many resting spores being capable of passing through the digestive canals of farm animals uninjured, or it may find its way into the ground by the decay of diseased turnips spread on the fields as food for animals. The highly infectious disease, clubbing or finger and toe, may be spread in this fashion, but it is also spread by infected soil being carried to other parts by farm implements, cart wheels, and the boots of farm labourers.

Inoculation.—Thousands of fungal spores, doubtless, come to rest upon the surface of host plants, but are unable to inflict injury because they cannot penetrate the external protective tissues. We consequently find that the leaf, which we have seen in our earlier work, has thin external membranes, is often the part attacked; leaf blotch, mildew, black rot, heart rot and the potato disease afford examples of this mode of entry. The delicate tissues of seedlings and flowers are affected similarly, as in cabbage rust and wheat smut respectively. The student will notice that exposed wounds are avoided amongst green plants by the formation of leaf scars (p. 94), and special protective growths (p. 109), but the development of the latter takes time; indeed, the germs of canker and coral spot frequently grow into the wounded bark of a tree before it has had time to heal. Any gaping wound in tomatoes affords an entry to the germ or spore of the black stripe disease in a like manner, whilst the roots of young plants, broken during careless transplanting, are especially vulnerable. Many cabbage plants thus become inoculated with black rot.

Roots are not particularly susceptible to disease, unless they are wounded. The white and violet root rots affect the roots of fruit trees and root crops respectively, and several diseases of the potato gain entrance through the tender sprouts, the eyes, and the young tubers, all of which have delicate external tissues.

Plants attacked.—Plants resemble animals in being susceptible to certain diseases, and immune from others. The question of immunity and its practical application will be dealt with below in considering the eradication of certain diseases. Fungi, however, differ very much among themselves as to the host plants in or on which they grow; for instance, the potato disease, the vine white rot, and the gooseberry mildew are diseases confined to the plants named. On the other hand, some fungal pests attack two plants indiscriminately, as in the cucumber and melon leaf blotch. In some cases the disease takes a different form according to the particular host plant inhabited; *e.g.* the potato leaf-curl and the black stripe of tomatoes are produced by identical germs.

Others, again, show a preference for one particular natural order or family of plants; thus the Cruciferae (cabbage, radish, etc.), are prone to attacks of white rust, finger and toe, and black rot, the Rosaceæ (many fruit trees) to white root rot, and the Gramineæ (cereals, etc.) to smut and bunt. In contrast to this we find diseases such as blackleg, sclerotium, and tree root rot occurring in plants belonging to several natural orders. In this connection the student should note that diseases like the root rots may frequently live upon weeds until a more suitable host plant is available.

Favourable Conditions.—Speaking generally, dull, damp warm weather is favourable to the development of plant disease, but there are exceptions to this statement. A drop in the temperature after a warm spell in Spring is favourable to the gooseberry mildew. Lack of ventilation aids in spreading winter rot among potato tubers which have been stored away damp, and also to the formation of "soft" foliage in cucumbers and similar plants, the leaves thus being easily penetrable by the leaf blotch fungus. Root rot is promoted by the soil being too damp; indeed, a water-logged soil has been found to be a very predisposing factor in the development of white root rot disease.

Symptoms.—Space precludes any lengthy descriptions of the numerous diseases. The young stem may be brown and wrinkled (potato black scab). Older stems may be stunted in growth (potato leaf curl), or marked with blackish stripes (tomato black stripe), or may have the bark cracked and partly destroyed (canker), or the vascular bundles showing as a black ring (cabbage black rot). There may be a fluffy mycelium developed between the bark and wood (white root rot) or near the base of the stem (sclerotium); in the latter disease sclerotia may be found inside the stem.

The leaf may be spotted to a varying extent. The spots may change colour from yellow to brown (potato disease) or to mauve (onion mildew), or greenish spots may turn brown and the leaf be dead within a day (cucumber leaf blotch). Long brown stripes may run a considerable distance along the leaf (barley blindness), the veins may be blackened (cabbage black rot), or sclerotia may be found embedded between the leaves of bulbs. The leaf itself may curl up (potato leaf curl), or there may be considerable distortion or malformation (white rust). Change of colour from a healthy green to yellow is a frequent symptom (root and heart rots), and is due to the fungus interfering with a proper water supply; this change of colour often precedes the shrivelling and death of the leaf. The surface of the leaf may be more or less enshrouded with mycelium (mildew) or with velvety mould (leaf curl and apple scab) which is sometimes extremely minute (potato disease), or there may be an eruption in the form of a series of concentric rings (white rust).

Fungal ravages upon roots give rise to internal decay (heart rot), as in mangolds, or to external malformation (finger and toe, or clubbing) as in turnips, where frequently several series of small tuber-like bodies are produced instead of one globular root, or to a complete investment of the root externally with a fluffy white or violet mycelium (white and violet root rot). Tree root rot shows itself by its clusters of yellow toad stools. Potato tubers may show scabs externally (potato scab and black scab), or they may be firm and hard (leaf curl) or shrivelled with white mouldy patches (Winter rot), finally becoming a putrid mass.

Diseased fruits may be invested with mildew (vine mildew) or with a glistening mildew changing to a dull brown (American gooseberry mildew). There may be black spores on the surface (bunt and smut), or dull silvery pimples may be present (vine white rot). Black patches on tomatoes indicate black stripe disease, black scabs and cracks on apples the apple scab disease, and the brown fruit rot causes ringed greyish tufts as well as brown patches upon the fruit.

Treatment.—The use of sound seed, grain, tubers, grafts, and new stock is of the utmost importance. Rape, turnip, and seeds of other cruciferous plants may be sterilised by soaking in dilute formalin solution for a quarter of an hour; this treatment frees them from black rot. A five to ten minutes' soaking frees the grains of cereals from adherent spores of smut, bunt, and blindness, whereas a two hours' immersion of potatoes is necessary to destroy the spores of scab. Leaf-curl is prevented if the tubers are lifted in an immature condition, whilst due regard to the proper drying of the tubers before storing in a ventilated pit does much to lessen the extent of potato disease and Winter rot. In grafting fruit trees no grafts should be taken from a tree suffering with canker.

Spraying with some fungicide is one of the most reliable means of preventing inoculation; Bordeaux mixture (a solution of lime and bluestone) sprayed upon potato plants, forms a thin film over the surfaces of the leaves, and prevents the spores of the potato disease gaining admission. Liver of sulphur is used similarly in the case of the gooseberry mildews, whilst Winter spraying of fruit trees with iron sulphate or copper sulphate tends to prevent brown fruit rot or apple scab

Well earthing or banking up potato plants prevents spores of the potato disease, washed down by rain, from reaching the tubers lying near the surface of the ground. A sprinkling of sulphur at the time of storing lessens the risk of Winter rot, and the same remedy dredged into the eyes at the time of planting keeps off the attacks of black scab. The risk of inoculation of cabbages by black rot present in the soil can be minimised by careful transplanting so as not to injure the roots. Beet and other root crops suffer much less from heart rot if they be lifted rather early, *i.e.* before the mycelium of the fungus has ramified down from the leaf stalks.

The eradication of weeds is very important. Weeds not only abstract nourishment from the soil, but also are convenient "hosts" upon which fungi can live between seasons. Prompt tarring of wounds will lessen the dangers of coral spot or canker. Fungi, such as the root rots, which are known to be present in some particular soil area, can be prevented from spreading by digging a trench about eight inches deep right round the infected area.

Infected soil requires careful attention. Sulphur placed in the trenches at the time of planting potatoes reduces the extent of potato scab; it has a beneficial effect upon roots afflicted with white root rot, and liver of sulphur is used as a spray for ground infected with American gooseberry mildew. Lime is the recognized remedy for finger and toe and violet root rot, but it encourages the growth of scab and black leg in potatoes. Thorough drainage of the soil keeps in check both white and violet root rot, drenching with iron sulphate restricts brown rot, whilst digging the ground over will tend to bury the resting spores of the gooseberry mildews.

Advantage may also be taken of the immunity of certain plants from particular diseases; thus by growing immune plants in an infected area, the fungus present in the soil may be starved for lack of nourishment. Cereals are not susceptible to black scab, black leg and violet root rot; turnips and carrots do not suffer from black scab. Red mangolds contract heart rot disease to a less extent than do yellow mangolds; this is an instance of varieties being susceptible to a different degree. No currants or gooseberries should be grown in ground known to be infected with American mildew until a period of two years has elapsed. Also an eight years' rotation should be practised upon ground infected with finger and toe.

All diseased parts of plants should be promptly burned. This is the only safe method of dealing with them. The formation of rubbish heaps should be avoided, since these are breeding grounds for many fungi. Pigs and other farm animals should not be fed with diseased "roots," for, as has been shown above, fungal spores may persist in the manure and refuse from piggeries and cowsheds. Decayed leaves and fallen fruit should be gathered and burned. In conclusion, it may be noted that two diseases—American gooseberry mildew and white root rot—have been scheduled by the Board of Agriculture, and all cases of their appearance must be notified to that body.

SUMMARY.

Fungi causing plant diseases usually consist of branched threads which bear one or more kinds of spores. They frequently pass the Winter in a resting stage. The spores are scattered by air, insects, rain, infected refuse, dung and receptacles. Inoculation may be through leaf, stem, root, fruits or tubers, especially through wounds or through delicate young parts. Fungi vary among themselves as to the plants they attack; they may confine themselves to plants of the same or of different kinds. Fungal diseases generally spread most rapidly during warm damp weather. The symptoms exhibited by infected plants are not confined to any particular part; they usually can be traced either to lack of nutrition of the host plant, or to the display of spores by the infecting fungus. Plant diseases are checked by the use of sound seed, by spraying with fungicides, by careful transplanting, by the eradication of weeds, by sterilisation of the soil, by rotation of crops and by other methods. The prompt destruction of all diseased material is essential.

Appendix III.

Preliminary Examination for the Certificate, April, 1909.

ELEMENTARY SCIENCE, SYLLABUS No. II.

Two hours.

You should answer SIX *questions.*

1. Show by a sketch the construction of a wet and dry bulb thermometer. Mark a likely position of the mercury in each of the thermometers on a still day when the leaves of plants show a tendency to flag, and on the evening of the same day when mist rises in the hollows.

2. What experiment would you make to ascertain the chief product of respiration of plants? With respect to roots, what particular ingredients in the soil does this product of respiration make soluble? How could you show this experimentally?

3. Give one example in each case of plants which possess :—
   (*a*) adventitious roots,
   (*b*) flowers of two different kinds,
   (*c*) leaves reduced to spines,
   (*d*) irregular flowers,
   (*e*) flowers in catkins—mention whether staminate or pistillate.

4. What experiments could you devise to show the paths taken by food materials in their passage upwards and downwards through the stem of a plant? Describe what would be seen in a transverse section of a herbaceous plant stem when looked at through a pocket lens.

5. Name and describe the different kinds of plants producing rosettes of leaves, which are to be found in a pasture.

6. If a carrot and a potato are left in the ground during a mild winter, what happens to each in the spring? Describe any experiments you would make in the laboratory on the digestion of carbohydrates.

7. Name a creeping plant known to you, which propagates itself by means other than seeding, and show by a series of drawings how it does so.

8. Describe the structure of an apple and show with sketches how the different portions of the fruit originate.

9. Give instances (two in each case) of plants which have flowers adapted to (*a*) long-tongued, and (*b*) short-tongued insects. Briefly describe, with drawings, the structure of each flower.

10. Describe any case you have noticed of cultivated plants being choked by weeds. Explain why the weeds were injurious.

11. Describe experiments or observations with which you are acquainted, which show that leaves are sensitive to the stimulus of light.

Examination for Certificate, December, 1909.

ELEMENTARY SCIENCE—SYLLABUS NO. II.

ELEMENTARY RURAL SCIENCE AND GARDENING.

Two hours.

You should answer SIX *questions, which must include at least* ONE *of the last two questions.*

1. How would you show that the leaves of a plant contain a substance which is able to convert an insoluble carbohydrate into a soluble carbohydrate?

2. Give an account of the life history of a mustard plant from the germination of the seed to the opening of the fruit, and point out in what particular its life history differs from that of a turnip.

3. Describe with the help of drawings, any experiments known to you on the transpiration of water by plants, and give any conclusions which might be drawn from them.

4. Describe the structure of the root of a plant, and give a brief account of the way in which it acts in the absorption of food

materials from the soil. What special structures are concerned in the process and how can their function be experimentally illustrated?

5. Describe with the aid of sketches the development of a crocus corm.

6. Upon what factors in the composition and properties of a soil and subsoil does the water content of the soil depend? Describe observations out of doors and experiments in the laboratory that you have made.

7. On a garden plot 5 yards by 3 yards, Savoy cabbages are to be grown. Describe the preparation of the ground, raising the plants from seed and subsequent treatment. Name the time of year suitable for each operation.

8. With the help of drawings describe how you would bud a rose tree. State what parts of the stem tissue must be taken with the bud and how the stock must be prepared for its reception.

* * *

Preliminary Examination for the Certificate,

April, 1910.

ELEMENTARY SCIENCE—SYLLABUS No. II.

Two hours.

You should answer SIX *questions.*

1. Explain fully what would happen as regards assimilation and the formation of chlorophyll in each of the following cases:—

(*a*) A growing plant with etiolated leaves is placed in the light in an atmosphere deprived of carbon dioxide, but at normal temperature.

(*b*) A growing plant with green leaves is placed under conditions similar to (*a*).

(*c*) A growing plant with etiolated leaves is placed in an atmosphere normal as regards composition and temperature.

2. Mention three wild plants and three cultivated plants which store a special supply of food for future use. Mention in each case the part of the plant in which the storage occurs, and the advantage to the plant of possessing such reserve materials.

3. What differences as regards form are noticeable in the cases of trees of the same species growing under the following conditions:—

(*a*) Solitary trees growing in the open.
(*b*) Trees growing in the middle of a forest.
(*c*) Trees growing on the margin of a forest.
(*d*) Trees growing on wind-swept uplands.

How would you account for the dissimilarity?

4. Give some account of the insects to be observed in a field of white clover in bloom, and describe the method of pollination of the clover flowers. How can you tell whether they have been pollinated?

Illustrate your answer by sketches.

5. How would you ascertain the temperature of the soil at a depth of one foot?

On a bright warm day would the surface of a heavy clay soil or that of a light sandy soil be usually the cooler? How would a covering of vegetation affect the temperature of a soil in summer and in winter? Give reasons for your answers.

6. Sketch the appearance of starch under the microscope. By burning it what do we learn of its composition? Give an account of experiments to show how it is converted into sugar (*a*) in animals, (*b*) in plants.

7. Sketch the apparatus you would use to find out what mineral salts are necessary for plant growth. Name any salt other than these which is necessary for animal growth.

8. Describe in detail an experiment to show that oxygen is essential to germination.

9. How would you prepare a seed bed? Give reasons for your procedure, and state what considerations would guide you in determining the depth at which to plant various kinds of seeds.

10. Describe, with the aid of drawings, the position and appearance of root hairs. What is their function, and how can this be experimentally demonstrated?

Examination for Certificate, December, 1910.

ELEMENTARY SCIENCE—SYLLABUS No. II.

ELEMENTARY RURAL SCIENCE AND GARDENING.

Two hours.

Answer SIX *questions,* TWO *of which must be selected from the first three.*

1. A garden crop of early potatoes is to be cultivated on land cleared the previous autumn. Give an account of the preparation of the land, the treatment of the seed potatoes, the method of planting and the after management. What precautions would you take for the prevention of disease?

2. Why are fruit trees grafted? Describe how the operation of grafting is carried out in the case of young fruit trees. Show by means of drawings the nature of the union of stock and scion after five or six years' growth.

3. Describe, with the aid of drawings, the preparation of geranium cuttings and the layering of carnations; show from what points the roots spring in both cases.

4. Briefly distinguish between rootlets and root hairs as regards size, position, appearance, structure and function. Illustrate your answer where necessary with sketches.

5. Mention two examples in each case of plants with the following characteristics:—

(*a*) Leaf tendrils.
(*b*) Underground stems.
(*c*) Flowers pollinated by the agency of wind.
(*d*) Biennials.
(*e*) Flowers which come out before the leaves.
(*f*) Food stored in specially modified leaves.

6. Describe with the aid of a drawing a longitudinal section through the middle of the flower of a bramble or wild rose; describe also the structure of the ripe fruit.

7. A leaf is exposed for some time to bright sunlight in air from which the carbon dioxide has been removed. It is then boiled in water, soaked in alcohol and finally placed in a solution of iodine. What effect is produced upon the leaf by these various liquids and what does the experiment prove?

8. Describe experiments which have shown that the growth of a plant is affected by the presence or absence of certain elements in the soil. State the chief results obtained.

* * *

Preliminary Examination for the Certificate, April, 1911.

ELEMENTARY SCIENCE—SYLLABUS No. II.

Two hours.

You should answer SIX *questions.*

1. Distinguish clearly between the function of the root and that of the leaf in the nutrition of the plant.

2. Some plants are grown for their fruits, others for their roots, leaves, &c.; which part of the plant forms the edible portion of the following:—(*a*) Broad bean, (*b*) French bean, (*c*) rhubarb, (*d*) asparagus, (*e*) lettuce, (*f*) Brussels sprouts, (*g*) vegetable marrow, (*h*) cauliflower.

3. Compare the structure of the flower of wheat or oat with that of gorse or violet, and show how the form of the floral organs in each of the two plants you select is connected with the mode of pollination.

4. What changes in the properties of a soil are produced when a crop is grown and dug under as a "green manure" for the succeeding crop?

5. Distinguish between thorns and prickles. Name two plants having the former and two plants the latter. Give some explanation of their value to the plant in each case.

6. The year after a railway bank had been repaired the following plants among others were observed to be springing up in the vacant ground:—Dandelion, coltsfoot, gorse, oak, sycamore, couch grass (twitch) and cleavers. What explanation can be given for the presence of these plants?

7. Describe, with the aid of drawings, the chief characteristics of the stem, leaves, buds, flowers and fruits of the ash and the birch.

8. Mention the names of plants which possess the following characteristics. Give two examples in each case of plants which have:--

- (*a*) Perfect flowers of two different kinds.
- (*b*) Foliage leaves of two different forms.
- (*c*) One cotyledon or seed leaf.
- (*d*) Leaves which are not fleshy, but are otherwise modified to withstand draught.
- (*e*) Flowers with both stamens and pistil, but no calyx or corolla.
- (*f*) Leaf buds which are formed underground.

9. Give the names of three bog plants or three salt marsh plants. In what respects do the three plants resemble or differ from one another, and in what relation do these characteristics stand to the environment.

10. How would you demonstrate the rate of growth of a bean root, and how would you investigate the stimuli which influence its direction of growth?

Examination for Certificate, December, 1911.

ELEMENTARY SCIENCE—SYLLABUS No. II.

ELEMENTARY RURAL SCIENCE AND GARDENING.

Two hours.

Answer SIX *questions,* TWO *of which must be selected from the first three.*

1. What kind of soil is best suited to the growth of carrots? What conditions cause forking of the roots? Describe the sowing of the seed, and state at what time of the year the seed should be sown. What subsequent cultivation is required, and when should the crop be ready to be gathered.

2. Make a table showing the proper distances for sowing, transplanting or singling early potatoes, late potatoes, parsnips, peas (three feet high), cauliflowers, broad beans, onions and celery; give in each case, in inches:—(*a*) The distance between the rows, (*b*) the distance between the plants in the row, (*c*) the depth to sow the seed.

3. If cabbages are grown too frequently on the same land, it is possible that they will suffer from a disease which attacks the roots. Name the disease and state under what conditions it is likely to appear, and what may be done to eradicate it.

4. By means of drawings, compare the leaves of peas, kidney beans and broad beans, and discuss the meaning of the notable differences among them. State why the end shoots of these plants are sometimes "nipped off."

5. On cutting across the stem of a plant, such as a sunflower, begonia or pelargonium, it is found, after a short time, that water exudes from the cut end of that part of the stem which still remains attached to the root. Account for this phenomenon and describe any experiment which will throw light upon it.

6. Compare the structure of the seeds of maize, wheat, oak and bean. Show in what respects they resemble or differ from one another. How would you classify these seeds, in respect of fundamental differences of structure? Give the essential characteristics of each class.

7. Describe carefully experiments which may be made to determine the extent to which soils are capable of absorbing and retaining water.

8. How would you demonstrate the conditions which determine the formation of starch in leaves?

INDEX.

Absence of leaves, 257
Absorbent power of soil, 310
Absorption conditions, 74
— of food, 69
— by roots, 74
— selective, 75
Acorn germination, 40, 41
—— structure, 11
Agents in soil formation, 284
Air, action on soil, 287
—— composition, 19
—— humidity, 29
—— spaces in leaf, 254
—————— water plants, 261
—— temperature, 31
Alder nuts, 225
Alluvial soils, 295
American water weed, 149
Amount of rainfall, 244
Anabolism, 49, 163
Analysis of soil, 306
Animal action on soil, 288
—— dispersal of seeds, 222
Annuals, 79
Annual rings, 105
Aphides, 391
Appendix, 372, 373
Apple fruit, 227
Arctic plants, 236
Arrangement of leaves in bud, 87
Arrowhead leaf, 265
Artichoke tuber, 117
Artificial manures, 360
Ascending sap, 167
Ash bud, 88
— fruit, 218
Aspiration, 175
Assimilation, 152, 164
Atmosphere purification, 160
Attraction of insects, 187, 191
Autumn wood, 105

Balsam fruit, 213
Banyan root, 60
Bark, 80
Barley germination, 45
Barometer, 27
Basalt, 292
Bast, 100
Bean germination, 37
—— lifting power, 38
—— plant, 1
—— plantlet, 8
—— rows of roots, 5
—— seed, 5-7
Bean seedling, 4
—— sowing, 364
—— twining stem, 133
Bedding, 369
Bee flowers, 195
Beech bud, 90
—— germination, 42
Beetles, 376
Beetroot, 57, 336
Berries, 225
Birch fruits, 218
Birds as seed scatterers, 225
Bi-sexual flowers, 186
Blackberry fruit, 226
Blackfly, 386
Bleeding of stems, 103
Bloom on fruit, 226
Blue flowers, 195
Branch, its history, 94
Branching of stem, 81
Breathing of plants, 160
Broad bean, 333
———— seed, 10
Bryony tendril, 135
Buckwheat germination, 43
Budding, 351, 365
Buds, 81
—— beech, 90
—— dormant, 95
—— elm, 89
—— elongating, 90
—— horse chestnut, 85
—— ivy, 83
—— plane, 85
—— protection of, 83
—— rhododendron, 90
—— rhubarb, 85
—— scales of, 86
—— sumach, 85
—— wheat, 89
Bulbs, 120
—— planting, 368
—— potting, 367
Burdock fruit, 225
Buttercup flower, 187

Cabbages, 331
Cabbage moth, 390
—— root fly, 386
Calcareous soils, 306
Calcite, 290
Calcium chloride, 172
Calvary clover fruit, 224
Calyx, 188
Cambium, 102

Cambrian, 298
Canopy of leaves, 238
Canterbury Bell flower, 195
Capillarity, 16
——— in seed, 18
——— in soil, 18, 309
Carpels, 179
Carrots, 337
Carrot fly, 384
Caterpillars, 388
Catkins, 182
Cauliflowers, 332
Cedar of Lebanon, 268
Celery, 339
——— earthing, 119
——— fly, 383
Cellulose, 105, 320
Centipedes, 392
Chafer beetle, 380
Chalk, 296
Channelled leaf stalks, 145
Chemical action on soil, 288
Cherry fruit, 226
——— flower, 196
Chlorophyll, 146
——— formation, 152
Chloroplastids, 146, 152
Clay, 291
——— soils, 306
Cleavers fruit, 224
——— leaf, 139
Clematis fruit, 215
——— tendril, 136
Click beetle, 374
Climbing root, 60
Clubbing, 338, 399
Coal measures, 297
Cobalt chloride, 166
Coiling of leaves, 257
Colorado beetle, 381
Colour of fruit, 225
——— soil, 283
Coloured light, 130
Columbine flower, 196
——— fruit, 213
Comfrey flower, 201
Competition, 233
Complex flowers, 190
Complexity of food, 52
Composition of air, 19
——— granite, 302
Compost mixing, 362
Conditions affecting moisture, 244
——— fertility, 313
——— germination, 16, 33
——— plant life, 270
Constituents of plants, 319
Contour of land, 246
Cork, 79, 109
Corms, 121
Corolla, 188
Crane fly, 381
Creeping stems, 112
Crocus corm, 121
———flower, 123
Cross pollination, 182, 201, 203
Cross and self pollination, 205
Culture solutions, 157
Cuticle, 254
Cuttings, 347, 365

Daddy longlegs, 381
Dandelion fruit, 214
Date germination, 46
Dead nettle leaves, 140
——— flower, 200
Density of soil, 311
Devonian, 298
Diamond back moth, 389
Diastase, 163
Dicotyledon, 47
Diffusion in seed, 18
Digestion, 53
Disposal of fruit, 209
Distribution of plants, 268
Division of herbaceous plants, 367
Dock fruits, 220
Dormant buds, 95
Double bell jars, 153
Drip tip, 145
Duckweed stem, 265
Dutch hoe, 359

Earthing, 119
Earth worms, 288
Ecology, 232, 281-2
Effect of light, 127
——— contact, 131
Eggs, 51
Elm buds, 89
——— fruits, 218
Elodea, 261, 149
Elongation of buds, 90
Environment, 234
Eocene, 296
Eosin, 166
Epidermis, 78, 165
——— of leaf, 144
Epiphytes, 251
Evaporation, amount, 168
——— from soil, 311
Evergreens, 255
Evolution of oxygen, 157
Examination questions, 402-409
Exclusion of insects, 201
Explosive fruits, 213
External appearance of stems, 78

Farmyard manure, 360
Felspar, 290
Female cells, 178
Fertility of soil, 312
Fertilization, 182
Fibres, 102
Fibrous roots, 57
Finger and toe disease, 399
Flea beetle, 377
Floating leaves, 265
Flowers, 176-207
Flowers and fruit, 280-1
Flowers in bud, 89
Flower seed sowing, 368

Food, 48-56
—— complexity, 51
—— manufacture, 163
—— tests, 52
Formation of chlorophyll, 152
French beans, 334
Frost on soil, 286
Fruits, 208-231
Fruit farm, 370
—— houses, 371
—— kinds, 208
Functions of stem, 78
Fungoid diseases, 373, 395

Geology, effect on distribution, 268
—— origin of soils, 294
Geranium fruit, 215
Germination, 16-47, 273-4
—— acorn, 41
—— barley, 45
—— beech, 42
—— buckwheat, 43
—— conditions, 16-34
—— date, 46
—— hemp, 45
—— honesty, 42
—— maize, 45
—— methods, 35
—— pea, 40
—— pine, 46
—— runner bean, 36
—— sunflower, 43
—— sycamore, 43
—— wheat, 45
Geum fruit, 222
Glacial deposits, 296
Glaciers as soil farmers, 287
Globular buds, 89
Globulin, 320
Glutin, 320
Gorse, 213
Grafting, 366
Grain maize, 13
—— wheat, 14
Granite, 292
—— composition, 302
Graphite, 290
Grass flowers, 186
Gravel, 291
Gravity action on root, 61
—— stem, 131
Greensand, 296
Green stems, 257
Grit, 291
Grooved stems, 257
Ground air, 25
—— amount, 25
—— composition, 25
—— movement, 26
Groundsel fruit, 215
Growth of roots, 75
Guard cells, 174
Gums and Resins, 320

Habitats, 270
of xerophyt, 248

Hairy fruits, 214
—— leaves, 254
Hairs in bud, 86
Hazel flowers, 185
Healing of wounds, 109
Heart and dart moth, 388
Heat from respiration, 22-33
Hedge climbers, 242
Hemlock fruit, 211
Hemp germination, 45
Hibernation of spores, 396
Hips, 229
History of a branch, 94
Hollyhock flower, 193
Honesty germination, 42
Honey guides, 198
Honeysuckle, 196
Hop tendrils, 135
Hornbeam fruits, 219
Horse chestnut bud, 85
Horsetails, 260-1
Humidity of air, 29
—— effect on transpiration, 174
Humus, 246, 303
Hydrophytes, 248

Ice action on rocks, 287
Igneous action on soil formation,289
Illumination, relative, 239
Inoculation of plants, 397
—— of soil, 313
Insect pests, 373
—— pollinated flower, 206
Insects' tongues, 190
Intensity of illumination, 239
Internal structure of leaves, 114
Iris stem, 114
Iron, 153, 290
Irritability, 61
—— of stems, 126-138
Ivy bud, 83
—— root, 60

Juicy stems, 98

Kalabolism, 49
King-cup flower, 186
Knots, 108

Laburnum seed, 10
Larkspur flower, 196
—— fruit, 213
Layering, 349, 367
Leaf, 279-280
—— arrangement on stem, 139
—— external appearance, 140
—— fall, 268
—— internal structure, 144
—— mosaics, 143, 141
Leaf-like stems, 257
Leaf stalk, 140
—— structure, 138-150
—— tendrils, 136
—— veins, 142, 149
—— work, 139
floating, 265

Leaf xerophytic, 254-7,
Legumin, 320
Lettuce, 329
Leukoplastids, 152
Lias, 297
Life history of fungus, 395
——————— insect, 374
Lifting power of bean, 38
Light, action on transpiration, 173
——————— stems, 126
——————— roots, 64
Lime and liming, 307
———fruits, 220
Limestone, 292, 297
Lime pan, 315
Liquid manures, 361
Loams, 306
Long and short stigmas, 201

Maize flowers, 182
——— germination, 45
——— grain, 13
——— root, 59
Male cells, 177
Man's effect on plant distribution, 268
Manures, 360
Marl, 292
Marsh marigold flower, 186
———————fruit, 213
———————ovary, 179
————plants, 235, 261
Mechanism of flowers, 190
Medullary rays, 107
Mercury, 166
Mesophytes, 248
Methods of germination, 35
Mica, 290
Milk composition. 50
Millipedes, 392
Minerals, rocks, 289
Mistletoe, 225
Modified evaporation, 168
Moisture available, 244
————influence on roots, 64
Moles, 289
Monkshood, 198
Monocotyledons, 47
Monsoons, 245
Moor pan, 315
Moths, 196, 388
Movement of protoplasm, 149
Mud, 291
Mullein fruit, 211

Narcissus bulb, 121
Nectaries, 198
Nitrates, action on plants, 323
Norfolk rotation, 325
Nutation, 131
Nutritive processes, 162
Nuts, 224

Oak flowers, 185
——leaf arrangement, 139
Ocean's action, 287
Onion bed preparation, 364
————bulb, 121
————fly, 382
Onions, 340
Oolite, 297
Orange berry, 226
Orchid root, 60
Organic agents in soil, 288
Osmosis, 69, 99, 163
Osmotically active substances, 167
Outdoor temperature, 33
Ovary, 178, 179, 188
Ovum, 179
Oxygen, 20
———— evolution, 157
———— necessary for respiration,22

Packing of leaves, 254
Palisade cells, 146
Pans in soil, 315
Pansy flower, 198
————fruit, 213
————ovary, 179
Parsley fruit, 211
Passion flower tendrils, 135
Path finders, 198
———of water in stem, 167
Pea germination, 40
Peas, 335
—— seed, 10
—— sowing, 364
—— tendrils, 137
Perennials, 79
Perianth, 186, 188
Petals, 188
Phloem, 100
Phosphates, 323
Photographic paper, 239
Photolysis, 160
Photosynthesis, 160
Pimpernel fruit, 211
Pine germination, 46
—— seed, 15, 215
Pink flower, 191
Pistil, 178
Piston mechanism, 205
Plane bud, 83
Plant action on soil, 288
Plant lice, 391
Plantain fruit, 211
Plant and environment, 232 272
——— ash, 320
——— associations, 238
——— food, 319
Planting trees, 362
Pliocene, 296
Plough pan, 315
Plum fruit, 226
Pollen, 178
———— box, 200
———— tube, 182
Pollination, 180
—————— of water plants, 260
Poplar flowers, 185
———— seeds. 215
Poppy fruit, 211

Porosity of soil, 309
Potash action, 324
Potatoes, 341
—— sets, 363
Potato starch, 119
—— tuber, 118
Potometer, 171
Potting, 363
—— seedlings, 369
Preparation of seed beds, 359
Pressure on ground air, 27
Prickly fruits, 222
Primrose flower, 201
Propagation, 347
—— by corms, etc., 354
Protection, buds, 82
Proteids, 100
Protoplasm, 48-9, 146, 163
—— requirements, 49
Pyrites, 290

Quartz, 290
Questions, Examination, 373
Rain, effect on ground air, 28
—— gauge, 28
Raspberry fruit, 226
Rate of root growth, 76
—— transpiration, 172
Reason for leaf fall, 268
Red ink, 166
Region of growth in roots, 75
Regulating action of protoplasm 169
Remedies for Plant diseases, 399
Respiration, 20, 160, 162
—— heat produced, 22-3
—— of seeds, 21
—— oxygen necessary, 22
Rhododendron bud, 90
Rhubarb bud, 85
Ring scars, 91
Rolling, 359
Roots, 275-6
Root absorption, 74
—— behaviour, 57
—— cap, 66
—— deep seated, 257
—— form and function, 77
—— growth, 75
—— hairs, 67
—— irritability, 61
—— ivy, 60
—— maize, 59
—— of water plants, 263
—— orchid, 260
—— pressure, 72
—— protection, 68
—— strong tissues, 68
—— structures, 66-9
—— swollen, 59
—— varieties, 57
—— work, 57
Rose fruit, 229
Rosette formation, 254
Rotation of crops, 324
Runner of strawberry, 113
Sachs' method, 153
Sand, 291
Sandstone, 291
Sap thick, 254
Scarlet runner, 335
Scars on stem, 90
Scattering of spores, 396
Seeds, 10-15
—— and fruits, 208
Seed, broad bean, 10
—— capillarity, 18
—— diffusion in, 18
—— laburnum, 10
—— pea, 10
—— pine, 15
—— respiration, 21-23
—— sowing, 361
—— structures, 5-15
—— sycamore, 11
—— vegetable marrow, 10
Self pollination, 182
Sepals, 188
Sexual cells, 177
—— reproduction, 176
Shale, 291
Shedding of leaves, 268
Sheet rubber, 160
Shingle, 291
Sieve tubes, 102
Silt, 291
Silurian, 298
Skip-jack beetle, 374
Slate, 292
Slugs, 393
Snails, 393
Snapdragon flower, 201
—— fruit, 211
Soil analysis, 306
—— and its preparation, 358
—— subsoil, 283
—— composition, 300
—— experiments, 317
—— fertility, 312
—— formation, 284
—— kinds, 305
—— percentage composition, 301
—— physical character, 305
—— properties, 309
—— temperature, 31
Solomon's seal stem, 115
Sowing flower seeds, 368
Special functions of stems, 112
Spongy cells, 146
Spring wood, 105
Staking, 363
Stalk of leaf, 142
Stamens, 177, 188
—— time of ripening, 193
Starch, amount produced, 157
—— formation, 153
—— in corms, 122
—— potato, 119
Stem, 78-138, 276-9
—— as conducting organ, 97-111
—— sensitive organ, 126-138
—— branching, 81

Stem, creeping, 112
—— duckweed, 265
—— eelworm, 375
—— external appearance, 78
—— functions, 78
—— green, 257
—— scars, 90
—— sensitive nature, 126
—— Solomon's seal, 115
—— special functions, 112-125
—— thickening, 104
—— vascular bundles, 97
Stencil, 155
Stigma, 182
Stimulus, 61
Stock flower, 191
Stomata, 165
    absent in water plants, 263
    sunken, 254
Stone fruits, 226
Storage of food, 53
—— starch, 163
Strawberry fruit, 227
—— stem, 112
Structure of seeds, 5-15
Struggle for existence, 236
Stunted plants, 254
Style, 182
Submerged leaves, 265
Subsoil, 283, 314
Succulence, 252
Suction power of stem, 166
Sugar in bulbs, 121
—— roots, 59
Sulphur, 290
Sumach bud, 84
Sunflower flowers, 203
—— fruit, 12
—— germination, 43
—— stem, 114
Sun's energy, 163
Sweet pea flower, 193
—— ovary, 180
Swollen roots, 59
Sycamore, arrangement of leaves, 140
—— flower, 186
—— fruit, 216
—— germination, 43
—— seed, 11
—— twig, 81
Symptoms of plant diseases, 398

Tap root, 57
Temperature and seed, 29
Temperature conditions, 267
—— effect on ground air, 28
—— soil, 288
—— of germination, 30-1
—— air, 31
—— soil, 31
—— outdoor, 33
—— variations, 33
Tendril, 131, 134-5
Tensions in tissues, 99
Tests for foods, 52
Thermal properties of soil, 310
Thermometer, wet and dry, 29
Thickening of stems, 104
Thick leaves, 255
Thin leaf tissues, 142
Thistle fruit, 215
Thorns, 254
Thrip, 386
Time of flowering, 186
Tobacco flower, 196
Tracheides, 149
Trachyte, 292
Transpiration, 165-175
—— current, 167
—— process, 170
Transplanting, 362
Trias, 297
Tubers, 116
    artichoke, 117
    potato, 118
Turgidity, 70
Turnip fly, 377
    moth, 388
    mud beetle, 379
Turnips, 338
Twining stems, 132

Underground stems, 114
Use of juicy tissues, 98
—— rake, 359

Variations in temperature, 33
Variegated leaves, 155
Vascular bundles, 97
Vaseline, 155, 165, 172
Vegetable albumin, 320
—— marrow seed, 10
Vegetative reproduction, 176
Veins of leaf, 254
Vessels, 105
Victoria regia, 265
Vine eyes, 370
Violet flower, 198
—— fruit, 213
Virginian creeper tendril, 136

Wallflower, 191
—— fruit, 211
Water-blob flower, 186
    culture, 231
    dispersal, 229
    evolved from leaves, 168
    lily fruit, 230
    plants, 235, 259
    action in soil, 284
Wax, 254
Wealden, 297
Weathering, 292
Weeds of soils, 316
Weevil, 376
Weight of starch, 157
Wet and dry bulb thermometers, 29
Wheat bud, 89
—— germination, 45
—— grain, 14
White grub, 380
Willow flower, 182

Willow herb fruit, 215
——— seed, 215
Wind and insect pollination, 206
—— dispersal of fruits, 211
—— drying effect, 245
effect on ground air, 26
- temperature, 267
transpiration, 174
—— pollination, 186
—— pollinated flowers, 206
Winged seeds and fruits, 215
——— stems, 257
Wireworms, 374
Wood, 100
——— absence in water plants, 263
Woodland society, 238
Woodsorrel fruit, 214
Woody fibre, 320
Work of leaves, 139
Worms, 374
Wounds, 109

Xerophytes, 248
Xerophytic characters, 251